Effect of Thermocycling on the Flexural Strength of Porcelain Laminate Veneers

Dissertation submitted to

THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY

In partial fulfillment for the degree of

MASTER OF DENTAL SURGERY

FEBRUARY-2005

BRANCH VI – PROSTHODONTICS

Dedicated to

The Almighty
Teachers and My Parents

In Concentration and silence, we must gather

strength for the right action.

- The Mother

Acknowledgment

First and foremost I would like to express my deepest gratitude to my teacher **Prof. E. Munirathnam Naidu, MDS,** for his unwavering guidance and immeasurable encouragement.

I consider it my privilege and honor to express my sincere and heart felt gratitude to **Dr. P. Jayakumar, MDS, Principal and HOD of Dept of Orthodontics**.

Indebted am I to my teacher **Prof. H. Annapoorni, MDS, Professor & HOD, Dept of Prosthodontics** for her help and guidance that has enabled me comprehend this work and reach its successful culmination.

My sincere thanks to my guide **Dr.G. Sivagami, MDS, Professor** for her constant encouragement, patient approach and liberty she provided me to carry out this dissertation.

I would like to extend my sincere and heartfelt thanks to **Dr. Sanjna**, for her suggestions and encouragement.

I also thank **Dr. Chandrasekharan Nair, MDS, Professor and HOD,** Dept of prosthodontics, AECS Maruti Dental College,

Bangalore**,** who has been and will be a source of inspiration to me and a whole generation of students, past, present and future.

A great deal of thanks goes to my teachers **Dr. Lakshmi, MDS, Dr. Padma Rekha, MDS,** and **Dr. Aruna, MDS** for their constant support and precious ideas.

I am grateful to **Dr. Madhan, Dr. Sashi, Dr. Sendil, Dr. Saphal, Dr. Sangeeta, Dr. Sridevi, Dr. Lakshmishree & Dr. Suchita** and all my fellow postgraduates without whose support, this study would not have been possible

Gratitude is due to **Mrs. Shanthi (Professor) Annamalai University, Chidambaram, Mrs. Vasanthi IIT, Chennai, Mr. Sreekumar, Scientific officer, Sri Chitra Thirunal Institute of Medical Sciences, Trivandrum, and Mr. A. K. Mathai, Biostatiscian** whose help made this study possible.

Last but not the least, I thank **Mr. Anand** and **Mr. Babu** who helped me to compile this work.

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Abstract

Aim

The aim of the study was to examine the impact of thermocycling on the flexural strength and development of surface flaws on the glazed surface of the porcelain laminate veneer restorations only and porcelain laminate veneers luted with resin cement.

Materials and Methods

80 Vitadur alpha dentin porcelain discs (10mm diameter, 0.9mm thickness) were made glazed on one side and divided into two Groups A and B, each containing 40 discs. The specimens in group A consisted of porcelain laminate veneer restorations only. Specimens in Group B had resin cement luted to their non-glazed surface standardized to cement thickness of 0.2mm. The discs in group A and B were then thermocycled at different temperatures and were subjected to SEM analysis to evaluate the effect of thermocycling on crack propagation. Mean flexural strength, was determined by ball on ring test.

Results

SEM analysis revealed crack propagation in the subgroups subjected to extremes of temperature (i.e) (4±1°C, 37±1°C) and (4±1°C, 65±1°C) in porcelain laminate veneers luted with resin cement. Flexural strength analysis revealed superior flexural strength for porcelain laminate veneers (88.58±6.94) when compared to porcelain laminate veneers luted with resin cement (8.42±2.60).In porcelain laminate veneer group, samples subjected to 37±1°C had superior flexural strength

(88.58±6.94) followed by sub groups 37±1°C and 65±1°C, 4±1°C and 37±1°C, 4±1°C and 65±1°C having (85.29±8.51, 74.47±7.19 and 71.34±7.91) respectively. In porcelain laminate veneer luted to resin cement group, samples subjected to 37±1°C had superior flexural strength (10.89±0.67) followed by sub groups 37±1°C and 65±1°C, 4±1°C and 65±1°C, 4±1°C and 37±1°C having (10.86±0.82, 6.09±0.72, and 5.84±0.81) respectively.

Conclusions

Fit of laminate veneers cannot be compensated by the thickness of luting agent. The flexural strength of porcelain laminate veneer decreases when luted with resin cement. Hence, a uniform thickness of ceramic with minimum thickness of luting agent must be ensured for the clinical longevity of porcelain laminate veneer restorations.

Introduction

Dental ceramics was introduced nearly one fifty years ago and it has stood the test of time with their superior properties like biocompatibility, surface hardness, light absorption, light scattering behavior and low electrical and thermal conductivity. In the course of evolution, attempts were made to strengthen the ceramics to overcome the inherent brittle nature. This has enhanced the possibility to use ceramics in thinner sections. Porcelain laminate veneers were thus developed and which is presently considered as a fine esthetic treatment option. The conservative, radical preparation executed in the making of crowns was eliminated to a greater extent by the laminate preparations which could change the shape and color of teeth. Ceramics are functioning in the wet environment of the oral cavity and they deteriorate by slowly generating cracks possibly due to the hydrolysis of silicate bonds. These flaws are further aggravated by the stresses induced by thermal variations that would happen within the oral cavity. Eventually, both the mechanical and chemical fatigue will lead to the failure especially in the case of ceramic laminate veneers.

Clinical failure of PLV restorations was due to the development of flaws on the glazed surface of the restorations. Surface imperfections act as a potential source of crack propagation

which may be either inherent in the porcelain or introduced during PLV manufacture, surface treatment or cementation. Post-operative cracking and failure of the restorations also occur as a consequence of thermal variations that these restorations are likely to encounter in service that has to be investigated. Further the resin cement used for luting the laminate veneer may impose surface changes on the veneer when subjected to thermocycling.

In the above context, we had designed an invitro study with the following objectives:

1. To examine the impact of thermo cycling on the development of surface flaws on the glazed surface of the restoration using scanning electron microscope.
2. To evaluate the biaxial flexural strength of the porcelain laminate veneers after subjecting to thermo cycling.
3. To evaluate the biaxial flexural strength of porcelain laminate veneers luted with composite resin after subjecting to thermocycling.
4. The influence of thermal variations of food and drinks on the survival probability of porcelain laminate veneers within 1 year of low level applied stress.

Review of Literature

Crim GA et al[1] compared the effectiveness of four thermocycling techniques, using two thermocycling systems. First system comprised of 4 baths with dwell times of 4 seconds in 60^0C bath, followed by 23 seconds at 37^0C, 4 seconds at 12^0C and 23 seconds at 37^0C. All baths were maintained within $\pm 2^0$C.Second system consisted of 2 baths maintained at 60^0C and 12^0C, $\pm 2^0$C with 30 seconds dwell time in each bath. The specimens were subjected to 1500 cycles in both the systems.

Fifty extracted premolars were prepared for a class-V restoration. The preparations were etched for 1 minute with 37% unbuffered phosphoric acid and were washed in running water for 1 minute. Then a composite filling was done. The restored teeth were placed in 37^0C water for 1 hour prior to cycling. Ten teeth containing restorations were randomly selected for testing by one of the following methods.

Method 1A - 4 bath cycle in dye (*basic fuschin*)

Method 1B - 4 bath cycle in water; dye immersion

Method 2A - 2 bath cycle in water; dye immersion

Method 2B - 2 bath cycle in water; (^{45}Ca) isotope Immersion

Method 3 - constant temperature; dye immersion

This investigation revealed that there was no significant difference among the four thermocycling techniques. The use of a dye or an isotope was equally effective and penetrated the tooth/ restoration interface to a similar degree. The extent of tracer penetration appeared to be independent of the dwell time in water baths. All procedures involving thermal changes were more potent in demonstrating leakage than the non-cycled methods.

Morena R et al[2] used the dynamic fatigue method to obtain sub-critical growth parameters. Fatigue in ceramics refers to growth of cracks aided by the combined influence of water and stress. The dynamic fatigue method which used a constant stressing rate was used to obtain sub-critical crack growth parameters for three dental ceramics. They are feldspathic porcelain, aluminous porcelain and a fine-grain polycrystalline core material. The constant stressing rate experiments were carried out at 37° C for all the three ceramics in distilled water, and for the feldspathic porcelain in artificial saliva as well. The feldspathic porcelain showed the lowest crack growth exponent, while the fine-grain ceramic showed the highest. Lifetime prediction curves showed that the fatigue failure within five years is a good possibility for feldspathic specimens at stresses which can be anticipated to occur in the oral environment. Little likelihood of failure was perceived for the fine–grain ceramic. The aluminous porcelain was intermediate between two materials with respect to failure probability.

Anusavice KJ et al[3] investigated the crack propagation resistance of two body porcelains as a function of incomplete sintering and determined their static fatigue by an indentation technique.

Two commercial products of feldspathic porcelain designated as C and V were selected. 3 bars of each porcelain 2×5mmx5.5mm were prepared and were underfired as much as 84^0C below their recommended firing temperatures. After the specimens were polished with 0.05µ alumina, cracks were induced with a Vickers microhardness indenter. If was found that semi-circular cracks produced with a load of 19.6N, grew when stored in distilled water at 37^0C.

Underfired ceramics exhibited a slight increase in fracture toughness and small change in pore volume. This was due to enhanced thermal shock resistance of the porcelain due to their reduced susceptibility to stress corrosion at the initial stage of crack propagation. Even when the firing temperature was decreased, moisture had little effect on slow crack growth because the pores were not continuous and they contained air not easily displaceable by water.

Anusavice KJ et al[4] found that tempering of glass produces a state of compressive stress in surface regions that enhanced the resistance to crack initiation and crack growth. This study determined the

influence of tempering on the sizes of surface cracks induced within the tempered surfaces of opaque porcelain-body porcelain discs with contraction co-efficient differences (*alpha O–alpha B*) of +3.2, +0.7, 0.0, -0.9 and 1.5ppm/°C. The discs were fired to the maturation temperature of 982°C and then subjected to 3 cooling procedures as slow cooling in a furnace (*SC*), fast cooling in air (*FC*) and tempering (*T*) by blasting the body porcelain surface with compressed air for 90s. The body porcelain discs were used as the thermally compatible control specimens. Crack diameter induced by a micro hardness indenter with an applied load of 4.9N at 80 points along diametral lines within the surface of body porcelain. Mean values ranged from 75.9μ to 103.3μ. The results indicated that differences in crack dimensions were attributed to the cooling rate, contract mismatch or their combined effect. It was also found that crack sizes for tempered specimens were much low when compared with fast–cooled and slow-cooled specimens.

Kelly JR et al[5] investigated fracture surfaces to understand failure mechanisms, source of the failure and to eliminate strength limiting flaws. They demonstrated that quantitative fracturography can be used to study failed aluminous and glass ceramic dental porcelains. Fracture surfaces of Dicor and Vitadur-N core porcelain modulus of rupture bars were studied to identify fracture mirror features which

were useful in locating the source of fracture and calculating the stresses at fracture in clinically failed restorations.

The morphology of fracture surfaces resulted from events related to the initiation and propagation of the crack front during failure. Modulus of rupture testing was performed in four point bending. Fracture surfaces were studied by scanning election microscope (*SEM*). The mean fracture stress of Vitadur-N porcelain was 94.7±12.4MPa and for Dicor the fracture stress was 55.4±10.6MPa. Fracture always initiated at the surface, usually at location involving porosity. Two sources of porosity are suggested for Dicor porcelain. They are casting porosity and porosity associated with an oriented crystal whisker reaction zone at the glass ceramming investment interface. Clinical Dicor porcelain crowns fail from the internal surface, often at an internal line angle.

Palmer DS et al[6] in their study suggested that thermocycling as a common method of testing dental materials to establish the suitability for in vivo use. There is no standard temperature adopted for dental material thermocycling. This study investigated the highest and the lowest temperature that can reasonably be achieved at the tooth surface by ingesting very hot and cold substances.

By using an intra oral digital thermometer probe, 13 human subjects were observed while they drank very hot and cold liquids. The temperature extremes produced were intraorally measured and adjusted for possible error. The results of this study suggest that a range of 0^0 to 67^0C may be appropriate for thermocycling dental materials.

White SN[7] demonstrated the existence of mechanically induced fatigue in feldspathic dental porcelain under ambient conditions. 30 test specimens 5x1x20mm were fabricated using 1gm of feldspathic porcelain powder (*vita VMK 68, Zahn Fabrik*) and VITA modeling fluid. The specimens were ground flat on one side with 120-grit alumina, washed with water, glued to a peterographic glass slide and sectioned with a slow speed diamond saw into samples of uniform thickness of approximately 1mm, using a peterographic thin section attachment. The 30 specimens were randomly assigned into 3 groups, one of 10 for cyclic load testing, one of 10 for testing the effects of ambient humidity, and one of 10 for flexural testing. Crack growth under repeated loading was characterized using an indentation technique. Microhardness tested with a Vickers pyramidal diamond was used to apply forces of 29.4N for 15 seconds. Indentation and crack lengths were measured using the microhardness tester, with four measurements per indentation. Each of 10 specimens was indented 10 times at the same location at 90

seconds intervals, under ambient conditions, with measurements made immediately after each indentation and after post-storage for 5 days. The mean elastic modulus was determined using 3 point flexural testing on 10 specimens from load deflection data.

Significant crack growth failed to occur when specimens were stored under ambient conditions in the absence of cyclic mechanical loading. The results showed that the feldspathic dental ceramic underwent mechanical fatigue when subjected to cyclic loading. Thus this effect of mechanical fatigue either alone or in combination with static chemical fatigue might have important implications to the longevity of these restorations.

Edge MJ et al[8] investigated whether the surface morphology i.e. surface cracking was affected by a variety of polishing and self-glazing treatments. They also investigated the theory that polishing and glazing porcelain surfaces of restorations reduced the wear on the opposing occlusion because of reduced roughness. To test this theory, samples of dental porcelains were prepared and subjected to various polishing and self-glazing treatments commonly used in dentistry and viewed under SEM. Fine cracks were discovered in the surface of the samples that had been polished and self-glazed. These cracks were typically greater than 50µm in length and depths were less than 20µm.

To establish the treatments responsible for the formation of these cracks, a more controlled study was performed. Samples of VITA VMK incisal porcelain were prepared and subjected to six treatments.

Treatment no. 1 → as-fired condition

Treatment no. 2 → Self-glazed

Treatment 3 & 4 → Wet ground followed by 1µm diamond polish.

Treatment 5 & 6 → Ground and polished using Shofu adjustment kit with 6 again self-glazed.

All the samples were observed using SEM. This study showed that polishing and then self-glazing the porcelain surfaces initiated formation of fine cracks to levels of 5100µm/mm^2. This cracking was not observed for specimens which were only polished or only self-glazed.

Giordano RA et al[9] compared the strengthening effect of the Tuf-coat ion exchange system with that of surface treatments such as overglazing, polishing and finishing. Eighty bars of feldspathic material, 3x3x30mm were formed in an aluminium split mould, sintered and randomly assigned to eight different surface treatment groups to examine these effects. The 8 groups were subjected to

self-glaze, heat treatment, Tuf-coat ion exchange, grinding and polishing, over-glaze, Tuf-coat ion exchange followed by self-glaze, Tuf-coat ion exchange followed by grinding and polishing, overglaze followed by Tuf-coat ion exchange respectively.

The ion exchange material significantly increased the flexural strength of porcelain relative to the self-glazed group. The strength increase generated by ion exchange was not statistically different from that in over glazed porcelain. Self glazing procedures after Tuf-coat treatment eliminated the strengthening effect of ion exchange. An increase in strength of approximately 43% was recorded for ion-exchanged porcelain. This increase may not be identical for all feldspathic porcelain because it depends on the composition of the porcelain, the exact amount of ion exchange material and press heating cycle.

Myers ML et al[10] investigated the stress corrosion fatigue characteristics of Optec-hsp porcelain. Disks (*1mm thick and 12mm in diameter*) were prepared according to the manufacturers recommendations. Dynamic fatigue was measured using a biaxial flexural strength test in a circulatory water bath. Samples were subjected to dynamic loading at multiple constant stressing rates like 100MPa/s, 10MPa/s, 1MPa/s, 0.1MPa/s and 0.01MPa/s. Inert strength was determined in a moisture-free environment at a

stressing rate of 100MPa/s. The wet strength values demonstrated a decrease in strength as the stressing rate decreases. This is because at higher stressing rates there is less time for crack growth to occur. The higher stressing rates resulted in higher fracture strength for the Optec porcelain. The dry strength specimens were not exposed to moisture, so crack growth caused by stress corrosion could not take place. Failure of these specimens resulted from the intrinsic flaw distribution resulting in higher strength. From this study, it was found that Optec-hsp is less fatigue susceptible than feldspathic porcelain and comparable to aluminous porcelain.

Giordano RA et al[11] characterized components of the Inceram ceramic system with respect to strength of the glass, alumina matrix and infused alumina by use of a four-point bend test. Flexural strengths of feldspathic porcelain and Dicor ceramic were also compared.

Inceram ceramic is based on formation of an interpenetrating network of alumina and glass. Results of flexural strength tests of Inceram ceramic components were of greater interest when the final strength of the infused material was considered. Sintered alumina matrix had strength of only 18.39±5.00MPa, which showed that the initial sintering was not responsible for the strength of the core. Logically, glass was the next material responsible for strength, but

the flexural strength was only 76.53±15.23MPa. But the overall strength was 236.15±21.94Mpa. There were several explanations for this drastic increase in strength. They were

- Due to a decrease in the total porosity by the infused glass.
- Strengthening mechanisms like crack deflection and crack bridging may also contribute.
- Compressive stresses around the alumina particles were also attributed to the strengthening effect.

Flexural strength of Inceram ceramic core, Dicor ceramic and feldspathic porcelain were also compared for strengths. There were two critical findings. First, Dicor strength was highly dependent on the presence of the Ceram layer. Removal of this layer with diamond polishing paste increased flexural strength by approximately 50%, which occurred during the fabrication of Dicor ceramic. Second, with respect to all-ceramic restorative materials, Inceram ceramic was the strongest core material.

Giordano RA et al[12] examined the effects of grinding and polishing on a feldspathic porcelain, an aluminous porcelain and a ceramic used in the Cerec system. A total of 105 bars of the feldspathic ceramic were made, randomly divided into 7 groups, and sintered according to the manufacturer's recommendations. The groups consisted of as fired, self-glazed, overglazed, ground,

polished, ground/annealed and polished/ annealed. A total of 45 bars of aluminous ceramic and Vitabloc MKI were randomly divided into 3 groups: as fired, ground and polished. Overglazing, grinding and polishing all significantly increased the flexural strength of the tested materials by 15 to 30%. Overglazing with a material having a lower coefficient of thermal expansion than that of the underlying porcelain increased the flexural strength, but the strength improvement was below the effects obtained from grinding and polishing during clinical procedures. The increase in the flexural strength of aluminous porcelain is even larger than the effect seen with the feldspathic porcelain. This is attributed to the crystalline nature of the ceramic i.e. since the aluminous material have crystals i.e. 50% the crystals were plastically deformed during the finishing procedures which lead to the development of compressive stresses around the crystals. A higher stress then had to be applied to cause the material to fail, since stresses induced inhibited crack propagation.

White SN et al[13] used blunt-indentation mechanics technique to investigate the response of a feldspathic dental porcelain to cyclic mechanical fatigue. The indentation stress-strain curve showed that the critical pressure necessary for crack initiation was 0.72GPa. This research also showed that subcritical pressures can also cause irreversible damage. A second series of experiment conducted by

them evaluated the strength loss. These experiments showed that the porcelain was susceptible to cyclic mechanical fatigue and the damage was cumulative. Also cyclic loading cumulatively decreased the strength of the specimen.

This test favored evaluating the evolution of damage because contact pressure increases monotonically from early linear elastic behavior to fully elastic-plastic regions. It provided controlled flaws for evaluating strength properties, with special insight into the stability or growth of natural flaws, and allowed for the study of crack initiation and crack propagation.

Harvey CK et al[14] investigated the failure mode involved during the traditional in vitro testing of glass-ceramic and determined whether the measured failure loads in those type of testing would be influenced by indenter radii and specimen thickness. Fracture surfaces and failure probability data from glass ceramic cuspid tested in a previous in-vitro study were examined to determine their mode of failure. 100 ceramic platelets–50 glass ceramic and 50 feldspathic porcelain were loaded to failure beneath spherical indenters (*radii 0.75 to 0.94mm*).

Glass ceramic cuspids failed from blunt contact damage at the point of loading. Such indentation damage was a unique response to localized contact stresses and was entirely a different failure mode from the cementation surface cracks which was reported for clinical specimens. Ceramic platelets exhibited failure from either the indentation surface (*hertzian cone cracking*) or from the supported surface (*mimicks bending failure*). It was found that the failure loads increased with the indenter radius for both failure modes. Failure from blunt contact damage occurred at markedly higher loads. Blunt indentation was identified as the failure source for the glass ceramic cuspid and a major failure mode for both feldspathic porcelain and glass ceramic platelets loaded beneath spherical indenters. The failure mode was not similar to that reported for clinically failed glass-ceramic crowns.

The testing variable which influenced the study were contact radius, ceramic thickness and surface finish of the ceramic specimen.

Cattell MJ et al[16] evaluated the biaxial flexural strength and reliability of four dental ceramics including: Empress glass ceramic (*EM*), Cerinate porcelain (*CE*), Corum porcelain (*CO*) and Alpha porcelain (*AL*) were compared. 20 disc specimens were prepared per material and overglazed. The piston on three ball test was used to test the specimens in a Universal testing machine at a cross head

speed of 0.15mm/min. It was found that mean strengths were 133.5±21.5 for EM; 109.1±11.3 for CE; 119.8±19.2 for CO; and 68.2±9.9 for AL. Weibull m-values included EM–6.60, CE–10.20, CO–5.27, AL–6.93. Cerinate thus had the highest m-value and therefore good dependability. Thus Empress was not stronger or more reliable than many of the frit materials.

Sobrinho LC et al[17] investigated the influence of fatigue on the fracture strength of Inceram, Optimal pressable ceramics and IPS empress in both wet and dry environments. 26 crown shapes measuring 8.0mm in diameter and 8.5mm in height were fabricated for each ceramic system. For each ceramic system, 10 specimens were tested for fracture strength without fatiguing. A second group (*8 specimens*) was submitted to fatigue regime of 10,000 cycles with minimum and maximum load of 20 and 300N and then it is fracture tested under dry conditions. A third group (*8 specimens*) was fatigued and fractured in a wet environment using a mechanical testing machine (*Instron*).

The strength of the three ceramic systems decreased significantly after fatiguing than non-fatiguing specimens either in a wet or dry environment. For the three systems fatigued in a dry environment and then fracture tested, Inceram and Optimal pressable ceramics was stronger than IPS empress, but no difference was found in the three systems fatigued in a wet environment.

Thus differences in fracture strengths of the different systems investigated may be due to the nature of the system and the environment in which the specimens were fatigued. Factors which were found to affect the strength of ceramics were

- Presence of stress corrosion cracking in high alumina systems.
- Moisture diffusion accelerated by the presence of interfaces.

Magne P et al[18] investigated the development of cracks in porcelain veneers using cyclic thermal fatigue. Maxillary incisors were restored with porcelain laminate veneers and subjected to thermocycling (5 *to* 50^0C) for 1000 cycles. Ceramic cracks were reported in 11 out of 27 specimens. Ceramic and luting composite thickness was measured after sectioning the teeth using SEM. Measurements were done at different locations like facial, incisal and proximal. Significant differences were observed in the ratio of the ceramic and luting composite thickness. The cracked sample exhibited a ratio at the facial location below 3.0, whereas non-cracked specimens were above this value (3.9 ± 1.0). It was found that the ceramic was thin in the facial aspect, which in turn was thinner than the incisal aspect. Thickness of composite was lesser in the cervical than in the incisal in the facial aspect. This study showed that cyclic temperature changes can cause development of flaws in porcelain veneers. They concluded that controlled tooth reduction

and the application of die spacers during laboratory procedures provided a sufficient and even thickness of ceramic combined with a minimal thickness of luting composite. This provided the restoration with a favorable configuration with regard to crack propensity (*i.e. ceramic and luting composite thickness ratio above 3*).Larger the cement thickness, the force exerted by the dimensionally changing cement decreased the strength of the ceramic. Shrinkage of the composite produced a static stress which in combination with cyclic thermal loads contributed to the failure of the feldspathic porcelain.

Chu FCS et al[19] investigated three methods for reducing surface roughness and improving the strength of porcelain restorations. 90 laminated In ceram/ vitadur alpha self-glazed porcelain disks were fabricated and randomly divided into three groups. Group 1, consisted of 30 specimens of original disks. Remaining 60 disks were then polished by 6 operators. Group 2 consisted of 30 of these polished disks. Groups 3 had the remaining polished disks which were reglazed. Average roughness values (*Ra*) of the veneers were measured using a profilometer. It was found that the Ra values were 0.5±0.1µm, 0.7±0.3µm and 0.4±0.1µm for Groups 1 to 3 respectively. Reglazed disks were also smoother than the original self-glazed disks (*P<0.01*). With the veneers placed in tension, the flexural strengths were 151±22MPa, 118±22MPa and 172±27MPa for groups 1 to 3 respectively.

This study concluded that reglazing polished porcelain surfaces significantly improved the surface texture and flexural strength of the materials tested.

Fleming GJP et al[20] investigated the implications of mixing variability on the slurry consistency used in the manufacture of dentine porcelain disc specimens for laboratory testing. 30 identical disc specimens were formed by condensing varying amounts of Vitadur-alpha dentine porcelain powder (*0.81g, 0.91g and 1.0g*) to a slurry consistency with a fixed volume of modeling fluid (*0.33ml*). The biaxial fracture strength of the disc specimens was then determined. It was found that the mean fracture strengths were 85.1, 87.3 and 81.9MPa for powder contents of 0.81, 0.91 and 1.0g respectively. Increasing or decreasing the powder content of the slurry from 0.91g resulted in an increase in porosity and a decrease in apparent solid density. The results suggested that an optimum consistency existed wherein consistent reproducible result was achieved. A comparison between materials can only be achieved if specimen preparation occurs consistently between centers and thus the results had implications in laboratory testing of materials.

As a consequence, it was proposed that the clinically induced variability in the dentine porcelain slurry consistencies can influence the longevity of dentine porcelain restorations. When

there was a deviation from the optimal consistency, there was a increase in the apparent porosity and surface imperfections which decreased the life span of the porcelain veneer restorations.

Scherrer SS et al[21] evaluated the effect of prolonged exposure to water on the mechanical properties like fracture toughness and flexure strength of low fusing ceramics. Disks and bars were mirror polished and annealed prior to aging in i) Air, Control; ii) Water for 50°C. Fracture toughness was determined by indentation fracture (*IF*) and indentation strength (*IS*) using a 19.6 N Vickers indentation by a three point bending at 0.1mm/min. It was found that both IS and IF showed a significant improvement in the fracture toughness of LFC after 8 weeks in water as opposed to the 24 hr values both in water and air. The origin of the observed result was unclear. Several explanations were given i) due to change in the surface structure ii) intricacies of crack lengths measurements. However for the flexural strength, the weibull characteristic (*So*) and the 'm' parameter showed no significant difference with water storage. The increase in toughness of Duceram LFC after aging in water was an interesting observation for a restorative material exposed to the oral environment but its important was not overemphasized, as its fracture toughness still remained in the lower range of currently available ceramic materials.

Aristidis GA et al[22] evaluated the clinical performance of porcelain laminate veneers for 5 years. 186 laminate veneers were placed in 61 patients aged 18 to 70 years, by a single operator following the same clinical procedure. At 5 years, 98.4% of the veneers were judged clinically acceptable. The retention rate was excellent, the fracture rate was low, and the maintenance of esthetics was superior. Also patient satisfaction was encouraging. The weak link in the porcelain veneer system is the composite luting agent. Only one of the restorations showed marginal defects at the restoration-luting composite interface because of loss of marginal seal and wash out of the luting agent. The study concluded that further research was required towards the improvement of marginal adaptation of porcelain veneers. It was concluded that the porcelain laminate veneers offered a reliable and effective procedure for the conservative and esthetic treatment of anterior teeth.

Bona AD et al[23] investigated the failure probability of monolithic and laminated ceramic structure from a four-point flexure test. This study tested the hypothesis that weibull moduli of single and multi-layer ceramics are controlled by the structural reliability of the core ceramic. Seven groups of 20 bar specimens were made from the following materials i.e. IPS empress, IPS empress 2, Evision, IPS empress 2 body, Evision core plus glaze layer, Evision core plus veneer plus glaze. Each specimen was subjected to four-point

flexure loading at a cross-head speed of 0.5mm/min while immersed in distilled water at 37^0C, except for one group where Evision core was tested in a dry environment (*vaccumed with nitrogen*). Failure loads were recorded and the fracture surfaces were examined using SEM. It was found that there were no significant differences in flexural strength among Empress 2, Evision core, Evision core with glaze and Evision core veneered with glaze and between empress 1 and glass ceramic. But there were differences in the flexural strength when it was tested in different environments i.e. flexural strength was more when tested in a dry environment compared to a wet environment. Glazing had no significant effect on the flexural strength or the Weibull modulus, which is measure of flaw size distribution for a given volume of ceramic under stress. In this study it was found that there was no difference in the flexural strength between core ceramic and core ceramic that is veneered. Therefore, it was concluded that the structural reliability of veneered core ceramic is controlled primarily by that of the core ceramic.

Flanders LA et al[24] investigated about the environments that could efficiently minimize machining induced damage of dental materials. Single point abrasion (*SPA*) scratch testing was used on five materials. They are feldspathic porcelain, MGC 1000, MGC 1120, Empress and Empress II. Scratch testing was done to determine the

scratch hardness and amount of edge chipping in different chemical environments like air, water, saline and glycerol solutions. Instruments used were a conical diamond indenter and a conventional tungsten carbide machining tool. It was found that water and saline yielded lowest scratch hardness values, air the next lowest and tests performed in glycerol yielded the highest hardness values. It was found that the hardness values measured with a conical diamond indenter in glycerine environment was twice than that measured in water and saline solutions. Environmental effects on chipping were minimal but a directly proportional relationship exists between load and percentage chipping for the tungsten carbide tool within the 10-50N test range. Effects of surface hardness was found to be more dependent on tool interactions rather than material specific properties i.e. diamond indenter removed more particles than the tungsten carbide tool. As a result, it may not be possible to utilize a particular single environment to substantially remove the damage response of dental materials to machining operations as the chemical environment had effect only on machining characteristics.

Fleming GJP et al[25] examined the impact of thermocycling on the development of surface flaws on the fit surface of porcelain laminate veneer restorations. Sets of Vitadur–alpha dentin porcelain discs (*15mm diameter, 0.9mm thickness*) were thermocycled at three

different temperature regimens i.e. between 4^0C and 37^0C; between 37^0C and 65^0C and between 4^0C and 65^0C, both on glazed and unglazed surfaces to simulate the conditions encountered in service. A control group was kept in water at 37^0C for a period of 3500 cycles as thermocycling was done for this amount of cycles. Mean fracture strengths, standard deviations and associated Weibull moduli (m) were determined using biaxial fracture (*ball on ring*). One way analysis of variance revealed no significant difference between means of porcelain specimens exposed to different thermocycling regimens.

However, a discontinuity existed at the lower strength values in the survival probability plots for porcelain specimen groups that were thermocycled. It was found that large flaws on the surface of the specimens may become extended due to the thermocycling regimens imposed. Further, the greater the tensile stresses imposed on the disc specimen surface by the thermocycling regimes, more likely the flaws are extended resulting in premature fracture. Consequently, the discontinuity in the survival probability distributions may be attributed to a different defect mechanism (*possibly by the extension of surface flaws*) superimposed on the distributions at these low values of strength.

Griggs JA et al[26] verified the formation of a hydrolyzed surface layer on Duceram LFC porcelain and determined the effect of such a layer on mechanical material properties including flexural strength, fracture toughness, surface micro hardness and surface elastic modulus. Specimens were fabricated from dentin porcelain by a vibration blotting technique and were prepared to have either blunt or sharp surface flaws. Half of the specimens underwent accelerated aging. Specimens were fractured in three-point flexure to measure their strength and fracturographic analysis used to determine fracture toughness and residual surface stress. Surface hardness and elastic modulus were measured using a micro indentation method. Porcelain surface topography was examined using atomic force microscopy to determine the composition of the surface layer. It was found that the aging treatment modified the porcelain surface topography, but did not create a layer with increased hydroxyl ion content. Porcelain strength increased upon aging, and the increase was proportional to the initial flow severity. The apparent toughness of sharp flaw specimens increased to match that of the specimens containing blunt flaws upon aging. Surface hardness and elastic modulus decreased upon aging. Modified surface layer was described as a remodeled surface because the severity of surface flaws decreased through a selective dissolution mechanism.

Thus, surface remodeling reduced the stress intensities of sharp flaws to match those of blunt flaws, which resulted in an increase in strength proportional to the initial flaws.

Geoffrey A Thompson[28] examined the influence of relative layer heights and displacement rate on the weibull parameters i.e. weibull modulus (m) and weibull characteristic (σ) of bilayered ceramic composite disks composed of In-ceram and Vitadur alpha porcelain.

Totally ninety specimens were fabricated and divided into 3 groups based upon the relative layer height of Inceram alumina and Vitadur alpha porcelain which was in the ratio 1:2, 1:1 and 2:1. Each group thus had 30 specimens and were tested in an equibiaxial ring on ring testing apparatus at different displacement rates of 0.127, 1.27 and 12.7mm/min. For the constant displacement rate, weibull parameters were significantly affected for the different relative layer heights. Many specimens exhibited non-brittle mode of failure i.e. they exhibited a fall followed by a rise in load before they underwent failure at low displacement rates.

This was due to the greater core thickness that exhibited effects of slow crack growth in laboratory equibiaxial tests. This study showed that the relative layer heights of laminate materials may have a significant effect on the reliability and longevity of those materials.

Materials and Methods

The present study was conducted to assess the effect of thermocycling on the flexural strength of porcelain laminate veneers.

Materials

- Vitadur alpha dentine porcelain.(*Vitazahnfabrik,Germany*)
- Modeling fluid
- 3M rely ARC luting resin cement

Instruments

- Metallic mold (*for disc fabrication*)
- Micrometer (*Mitutoyo*)
- Electronic weigh balance (*AND series HL-200*)
- Heatless silicon carbide green stones
- Slow speed micromotor (*Kavo EWL*)
- Artery forceps
- Spatula for mixing composite
- Metallic fixture
- Emery discs – in grades of 500, 600 and 800

Equipments

- Multimat vaccum furnace (*MACH 2 Dentsply*)
- Thermocycling unit
- Scanning electron microscope
- Universal testing machine(*Instron)*

METHODOLOGY

a. Fabrication of the test specimens

80 test specimens were fabricated in the form of discs of 10 mm diameter and 0.9 mm thickness. About 0.6gm of the Vitadur alpha dentine powder (*fig.1*) preweighed in an electronic balance (*AND series HL 200*) (*fig.2*) and 0.22ml of modeling fluid measured in a micropipette was used.

The ceramic powder was mixed with modeling fluid, placed in the metallic mold (*fig.3*) and compacted. The discs were then fired in a Multimat vaccum furnace (*Mach 2 Dentsply*), (*fig.4*) according to the manufacturer's instructions.

Firing cycle

Sintering was done according to the manufacturer's recommendations.

Table I: **Firing cycle**

Air fired	600^0C for 360 seconds
Vacuum fired	970^0C for 60 seconds
Air fired	970^0C for 60 seconds

Glazing procedure

Table II: Glazing cycle

Preheat time	3 minutes
Dry time	3 minutes
Low temperature	650^0C
High temperature	940^0C
Heat rate	50^0C
Hold time	2 minutes

The specimens were verified for dimensions using a micrometer (*fig.5*). Heatless green carbide stones and emery discs (*fig.6*) were used to reduce the ceramic thickness. Specimens (*fig.7*) were divided into two groups of 40 specimens each. (*i.e.*) Group A (*porcelain laminate veneer*) and Group B (*laminate veneer luted with resin cement*). Test specimens of Group A were prepared as mentioned above. Group B specimens had resin cement luted with

the laminate veneers. First, the discs of 0.9mm thickness and 10mm diameter were prepared. Unglazed surface of the discs were then etched with 5% hydrofluoric acid for 60 seconds. It was then washed thoroughly in water and luted to a dual cure resin cement standardized to a thickness of 0.2mm with the help of a metallic shim.

Test specimens from each Group (*i.e.*) A and B were again divided into four subgroups according to the different temperatures employed for the thermocycling procedures. They are

- Sub group (i) – 37^0C (*control*)
- Sub group (ii) – between 4 and 37^0C
- Sub group (iii) – between 37 and 65^0C
- Sub group (iv) – between 4 and 65^0C

Table III: Distribution of specimens

	Group – A (*Porcelain Laminate veneer*) n=40				**Group – B** (*Laminate veneer Luted with resin cement*) n= 40			
Sub- Group	(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
No of Samples (n)	10	10	10	10	10	10	10	10

b. Thermocycling procedure

Thermocycling was done for both A and B groups. Each group had 4 subgroups of 10 specimens each. The sample specimens of each sub-group were thermocycled between the maximum and minimum temperatures that the mouth is subjected to (*65±1^{0}C and 4±1^{0}C, respectively*) and closed mouth temperature (*37±1^{0}C*). The samples of sub-group (ii) of (*A and B*) were thermocycled between 4±1^{0}C and 37±1^{0}C. Samples of sub-group (iii) of (*A and B*) and samples of sub- group (iv) of (*A and B*) were thermocycled between (*37±1^{0}C and 65±1^{0}C*) and (*4±1^{0}C and 65±1^{0}C*), respectively. Samples were carried in a mesh tray embedded in silicone putty impression material to expose only the glazed surface. A control group of samples belonging to sub-group (i) of (*A and B*) was submerged in a water bath maintained at 37±1^{0}C for the time equivalent to 3500 cycles. The mesh tray was submerged in each water bath for a constant time (*5 seconds*).

Thermocycling unit (*fig.8, 8a*) was custom fabricated. It consisted of a thermocouple and a heating element. A temperature sensor kept in the water bath was connected to a digital display unit. The digital display unit had a set button through which the temperature could be accurately set to ±1^0. When the water bath attains the desired temperature, the thermocouple automatically cut

off the power supply and thereby maintaining the set temperature. Temperatures of 37 ± 1^0C and 65 ± 1^0C were set with this unit.

Temperature of 4 ± 1^0C was maintained with the ice pack containing crushed ice and temperature measured through the thermometer.

The frequency of the thermocycling regime proposed in the study was based on the assumption that at most 10 extreme thermocycling cycles would occur per day. As a result, 3500 cycles chosen would represent approximately one year of service for a porcelain laminate veneer restoration.

c. Evaluation of surface topography using scanning electron microscope

The objective of using a scanning electron microscope (*fig.9*) was to find out the surface changes imposed by the thermocycling regime on the test specimens. Each specimen in subgroups (i), (ii), (iii) and (iv) of both groups A and B were subjected to scanning electron microscope analysis after they were thermocycled. The specimens were prepared by platinum sputtering (*fig.10*). Their surface topography was analyzed using ×100, ×500 and ×1000 magnifications.

d. Evaluation of the flexural strength of laminate veneer

A ball on ring test was employed to assess the fracture strength of the surface finished specimens. The test was performed using a Universal testing machine (*Instron*) (*fig.11*). A loading ring apparatus with a diameter of 1.4mm and a support ring of 10mm diameter were custom fabricated (*fig.12*).

The specimens were placed on the support ring apparatus fixed to the Instron testing machine. The displacement rate of the Instron testing was standardized at the rate of 1.0mm/min to ensure that the fit surface of the disc was loaded in tension.

The breaking load values were obtained and the flexural strength of all the test specimens was calculated using the Timoshenko's equation which is

$$\sigma \max = \frac{P}{h^2} \left\{ (1 + \upsilon) \left[0.485 \ln \left(\frac{a}{h} \right) + 0.52 \right] + 0.48 \right\}$$

where

P = load at fracture in Newton

t = thickness of the specimen (0.9mm)

a = radius of the circle of support (5mm)

ν = Poisson's ratio of ceramic. (0.25)

e. Evaluation of flexural strength of laminate veneer luted with resin cement

Timoshenko's equation assumes a uniform elastic modulus and Poisson's ratio throughout the entire disc and for this reason, it could not be used in this form to calculate the biaxial flexural strength of the two layer discs. First, the position of the neutral plate was calculated (h_n) and then a value for elastic modulus (e_0) and Poisson's ratio (n_0) was obtained, to represent the entire two layer disc (i.e.) ceramic luted with resin cement .Finally, the biaxial flexural strength was assessed by evaluating the following equation:

$$BFS_{bi} = \frac{2\,\varepsilon_1\,(1-\nu_0)\,BFS\;\;(T - h_n)}{\varepsilon_0\,(1-\nu_1)\,T}$$

Where

BFS is the flexural strength obtained

T = thickness of the disc (1.1 mm)

h_n = height of the neutral line from the top (0.55)

ε_1 = elastic modulus of the resin cement (5 GPa)

ν_1 = Poisson's ratio of resin cement (0.24)

ε_0 = elastic modulus of the ceramic material (107 GPa)

ν_0 = Poisson's ratio of ceramic material (0.25)

f. Statistical analysis

A one way analysis of variance (*ANOVA*) was applied to the biaxial fracture strength data because there were more than 2 sets of data to compare. The one-way ANOVA was employed to reveal

significant differences between the means of the three thermocycled porcelain disc specimens and specimens luted with resin cement. Student's t-test was used to find out the difference between strength values of the thermocycled porcelain discs and discs luted with composite and with that of the control groups. Kaplan Meier's survival probability analysis of Group A and B was also done.

Fig1: Vitadur alpha dentine powder, modeling fluid and resin cement

Fig2: Electronic weigh balance

Fig3: Metallic mold

Fig4: Multimat vacuum furnace

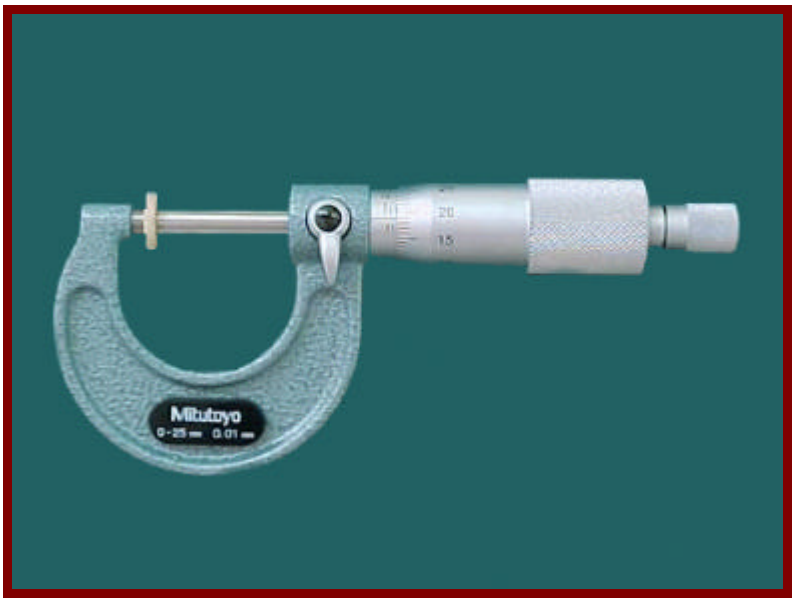


Fig5: Micrometer

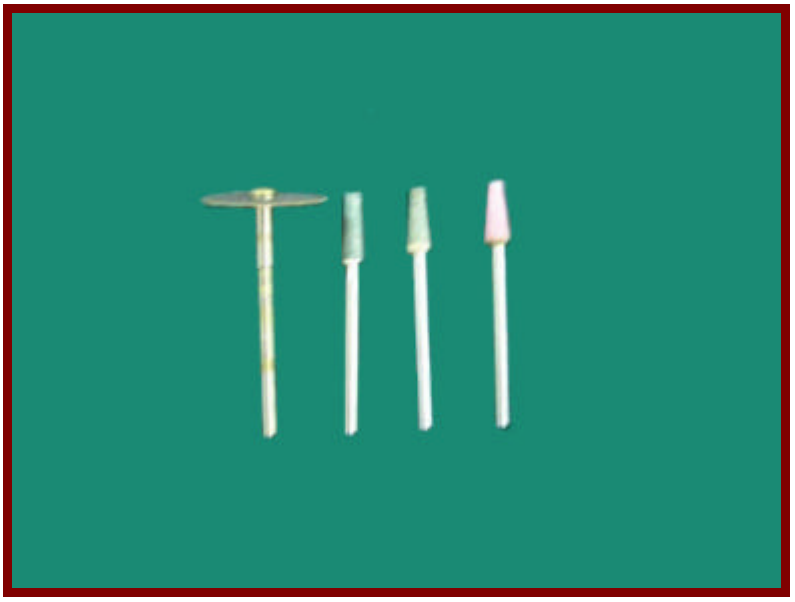


Fig6: Heatless Green Carbide Stones & Emery Disc

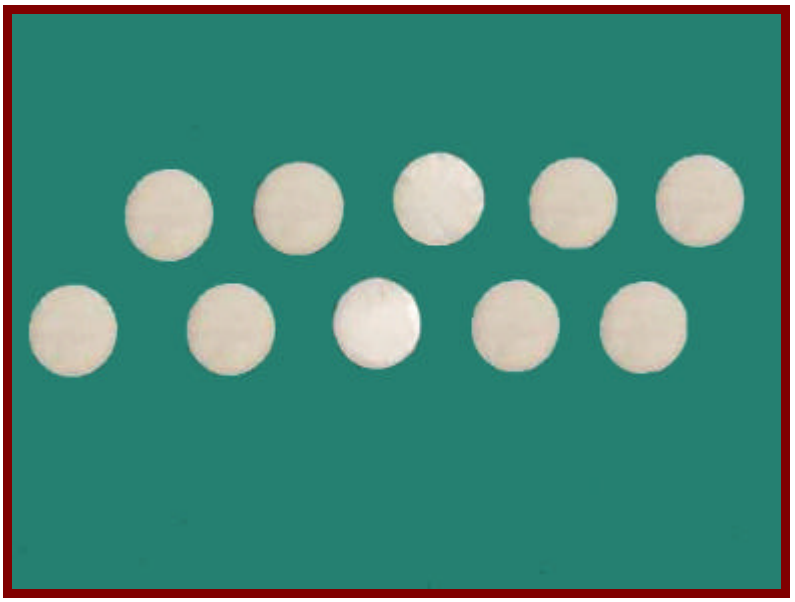


Fig7: Ceramic samples

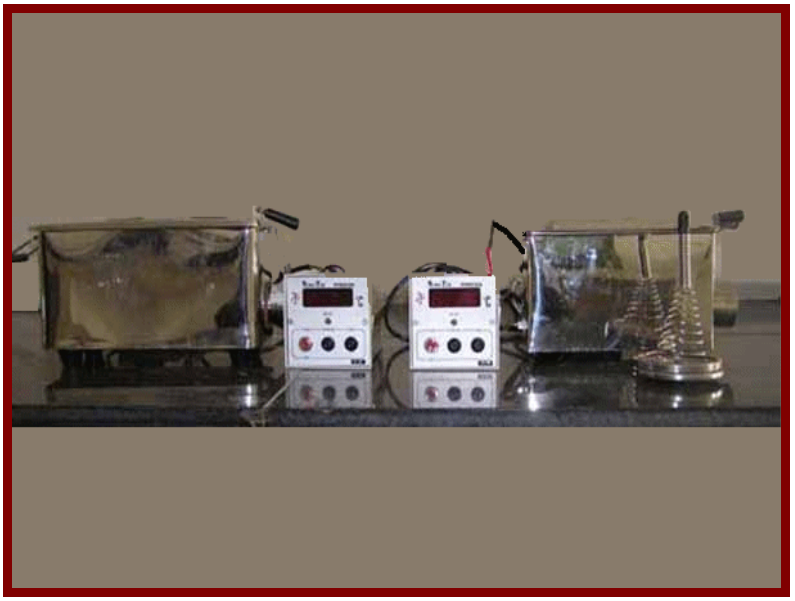


Fig8: Thermocycling unit

Fig8a: Sensor and thermocouple in thermocycling unit

Fig9: Scanning Electron Microscope

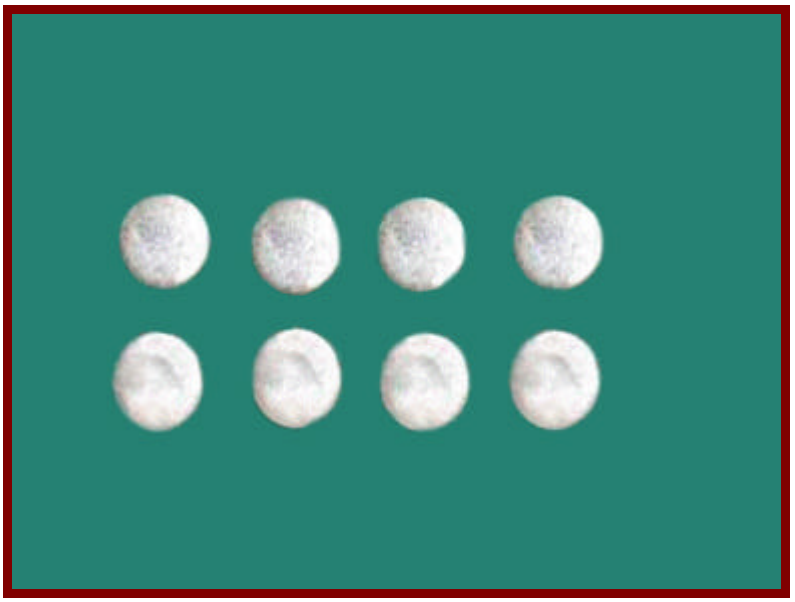


Fig10: Platinum sputtered specimens for SEM

Fig11: Instron Testing Machine

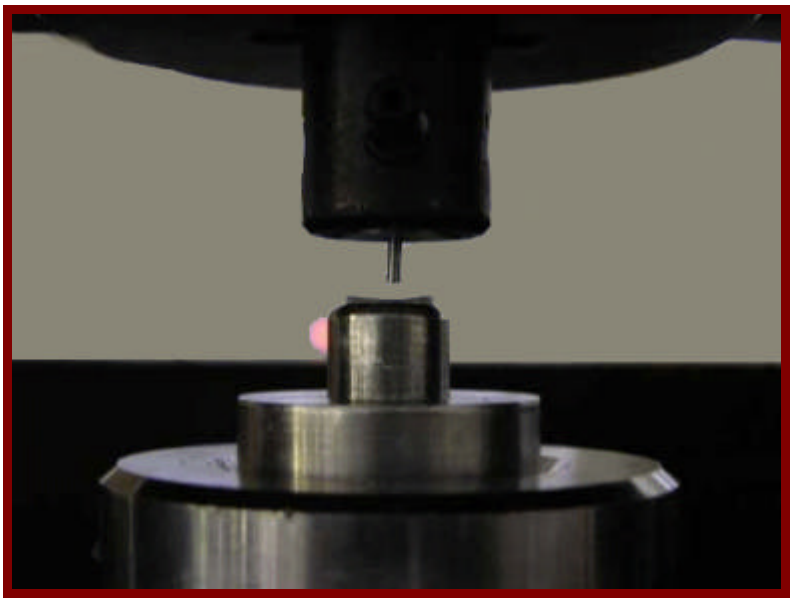


Fig11a: Metallic Fixture in Instron Testing Machine

Fig12: Metallic Fixture

Fig13: Micromotor

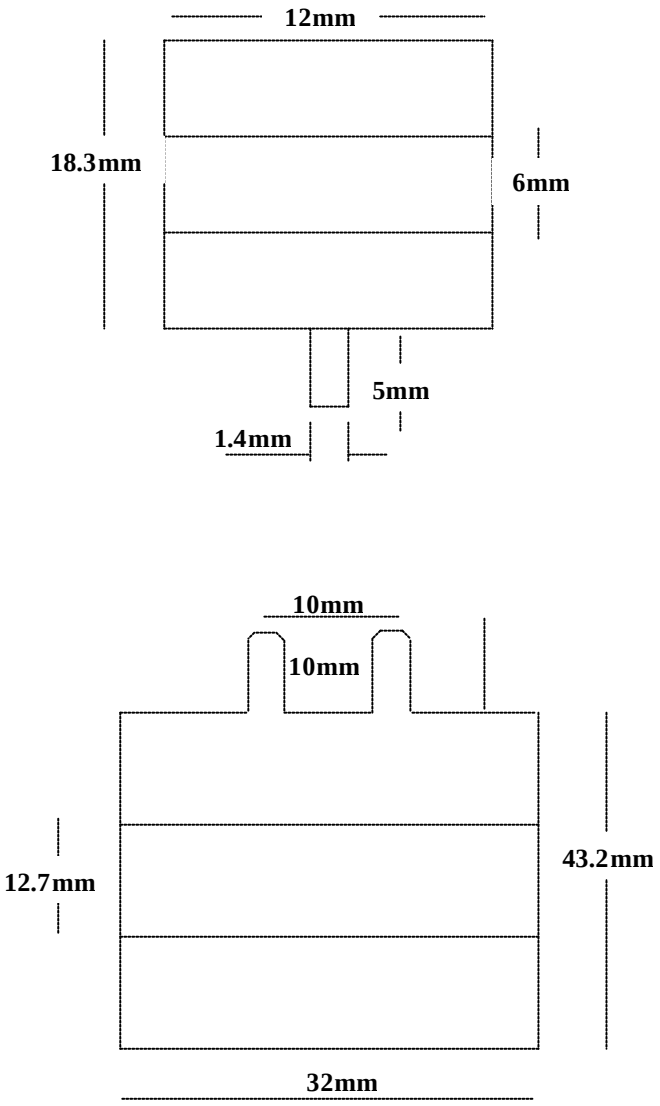
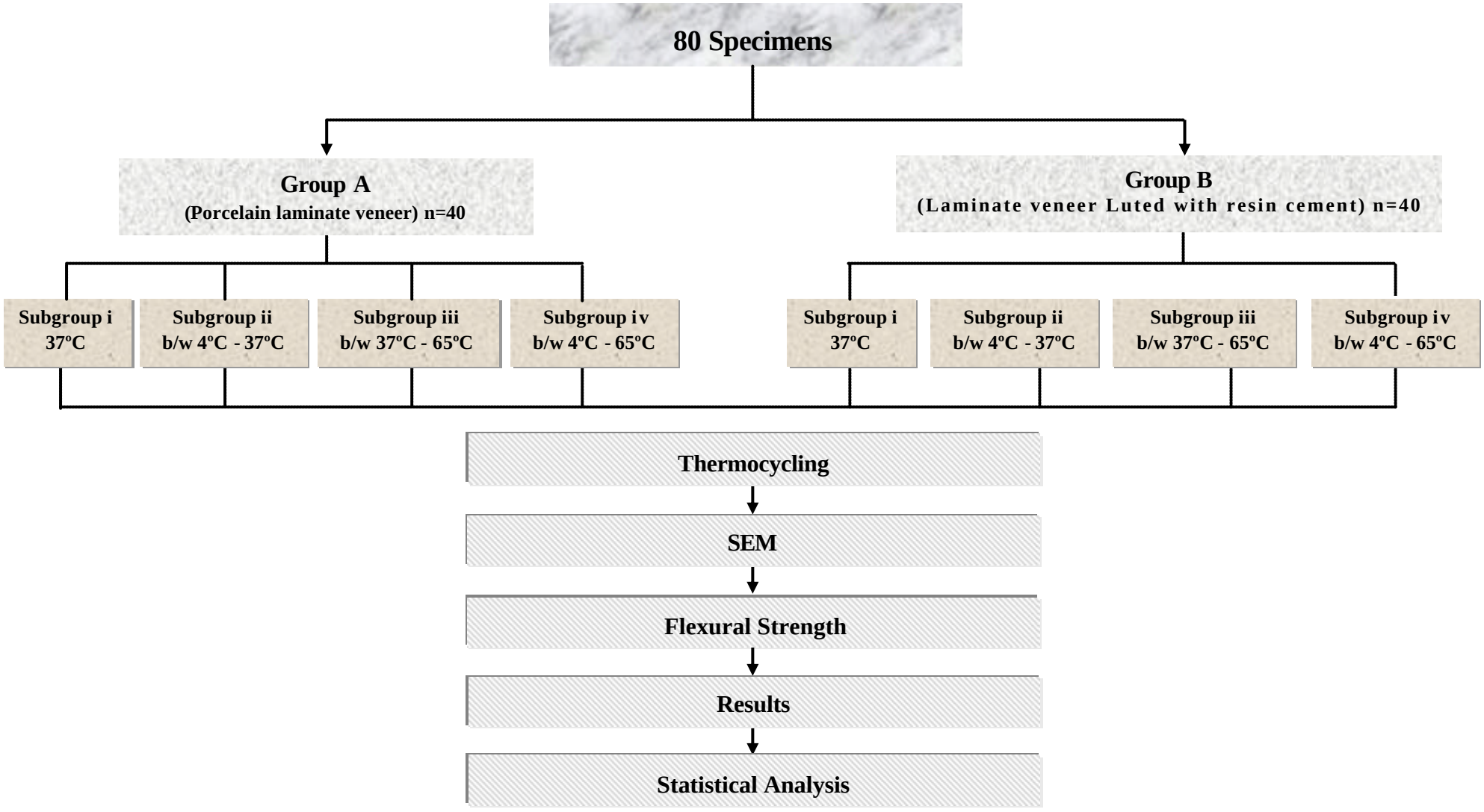


Fig12a: Fixture for Holding Ceramic Disk in an Instron Testing Machine

Flow chart


80 Specimens
Group A
(Porcelain laminate veneer) n=40
Group B
(Laminate veneer Luted with resin cement) n=40
Subgroup i
37ºC
Subgroup ii
b/w 4ºC - 37ºC
Subgroup iii
b/w 37ºC - 65ºC
Subgroup iv
b/w 4ºC - 65ºC
Subgroup i
37ºC
Subgroup ii
b/w 4ºC - 37ºC
Subgroup iii
b/w 37ºC - 65ºC
Subgroup iv
b/w 4ºC - 65ºC
Thermocycling
SEM
Flexural Strength
Results
Statistical Analysis

Results

80 Vitadur alpha dentin discs were fabricated and was divided into 2 groups A and B based on whether there is ceramic veneer only (Group A) or whether there is ceramic veneer luted with resin cement (Group B).They were then divided into 4 sub groups based on the temperatures that they were subjected to thermocycling. Breaking load values were obtained and flexural strength was calculated. SEM analysis was performed to evaluate the effect of thermocycling on crack propagation.

The results are tabulated and statistically analyzed using student's t-test and one-way ANOVA. Kaplan Meier's survival probability analysis was done to find the survival probability of the sub groups.

Flexural Strength Analysis

Table-IV: Flexural Strength of Group A specimens

Test Samples	Sub Group (i)	Sub Group (ii)	Sub Group (iii)	Sub Group (iv)
(n)	Flexural Strength (MPa)	Flexural strength (MPa)	Flexural strength (MPa)	Flexural strength (MPa)
1	86.31	85.62	84.52	78.54
2	96.70	71.51	94.39	57.41
3	81.87	69.75	78.20	69.59
4	78.41	77.41	92.63	73.18
5	95.98	81.90	90.58	79.27
6	83.05	84.10	87.62	69.62
7	93.84	71.06	90.74	75.89
8	92.32	68.54	69.54	61.53
9	82.16	69.14	74.10	66.70
10	95.12	65.65	90.53	81.66
Mean	**88.58**	**74.47**	**85.29**	**71.34**
SD	**6.94**	**7.19**	**8.51**	**7.91**

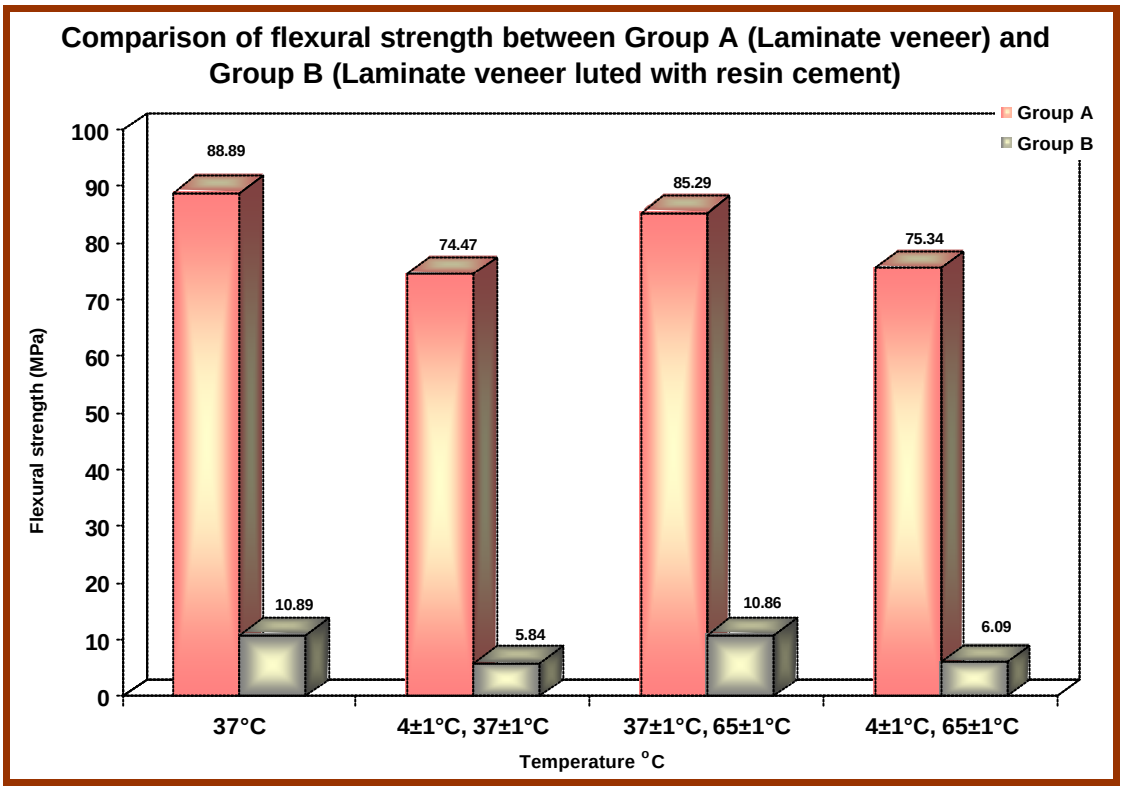
Table-IV shows the flexural strength of samples of Group A specimens. Sub groups **(i), (ii), (iii)** and **(iv)** were thermocycled at 37^0C, (4 ± 1^0C) and 37 ± 1^0C), (37 ± 1^0C) and (65 ± 1^0C) and (4 ± 1^0C) and (65 ± 1^0C) respectively. It was found that sub-group (i) had superior flexural strength followed by sub-groups (iii), (ii) and (iv).

Table-V: Flexural Strength values of Group B specimens

Test Samples	Sub Group (i)	Sub Group (ii)	Sub Group (iii)	Sub Group (iv)
(n)	Flexural strength (MPa)	Flexural strength (MPa)	Flexural strength (MPa)	Flexural strength (MPa)
1	09.80	5.61	09.08	7.01
2	11.64	4.99	11.67	5.44
3	10.35	5.45	10.03	5.43
4	11.04	7.01	10.46	4.99
5	11.52	5.38	11.54	6.78
6	11.67	6.77	10.95	6.63
7	10.83	7.04	10.71	6.83
8	11.43	5.78	11.25	5.51
9	10.19	4.82	11.43	5.91
10	10.47	5.52	11.49	6.35
Mean	**10.89**	**05.84**	**10.86**	**06.09**
S.D	**0.67**	**0.84**	**0.82**	**0.72**

Table-V shows the flexural strength of samples of Group B specimens. Sub groups **(i), (ii), (iii)** and **(iv)** were thermocycled at 37^0C, (4 ± 1^0C) and (37 ± 1^0C), (37 ± 1^0C) and (65 ± 1^0C) and (4 ± 1^0C) and (65 ± 1^0C) respectively. It was found that sub-group (i) had superior flexural strength followed by sub-groups (iii),(iv) and (ii)

Graph-1



Flexural strength values of Group-A (*laminate veneer*) and Group-B (*Laminate veneer luted with resin cement*) are compared. It is found that the samples of Group-A (*laminate veneer*) of all the subgroups **(i, ii, iii** and **iv)** exhibit a superior flexural strength than the samples belonging to Group-B (*laminate veneers luted with resin cement*).

Statistical Analysis

Table-VI: Mean, Standard deviation and test of significance of mean values between Control and different subgroups of Group A

Subgroups Compared	Mean ± SD	p-value*
Subgroup(i) Vs (ii)	88.58 ± 6.94 74.47 ± 7.19	< 0.0001 (Sig.)
Sub group(i) Vs (iii)	88.58 ± 6.94 85.29 ± 8.51	0.36 (NS.)
Sub group (i) Vs (iv)	88.58 ± 6.94 71.34 ± 7.91	< 0.0001 (Sig.)

* Student's independent t-test was used to calculate the p-value.

Mean value in subgroup **(i)** is significantly higher than the mean values of subgroups **(ii)** and **(iv)**. However, there is no significant difference in mean values between subgroup **(i)** and subgroup **(iii)**.

Table-VII: Mean, Standard deviation and test of significance of mean values between subgroup iii Vs subgroups ii and iv of Group A

Subgroups compared	Mean ± SD	p-value*
Subgroup (iii) Vs (ii)	85.29 ± 8.51 74.47 ± 7.19	< 0.05
Subgroup (iii) Vs (iv)	85.29 ± 8.51 71.34 ± 7.91	< 0.05

* One way ANOVA was used to calculate 'p' value

One way ANOVA was done to compare the mean values of subgroups **(ii)**, **(iii)** and **(iv)** of Group A. It was found that the mean value in Group **(iii)** was significantly higher than the mean values in sub groups **(ii)** and **(iv)**.

Table-VIII: Mean, standard deviation, and test of significance of mean values between subgroups (ii) and (iv) of Group A

Sub groups Compared	Mean ± SD	p-value*
Sub group (ii)	74.47±7.19	0.37(NS)
Sub group (iv)	71.34±7.91	

***** Student's independent t-test was used to calculate the p-value.

There is no significant difference in mean values between sub-group (ii) and (iv) of Group A.

Table-IX: Mean, Standard deviation and test of significance of mean values between Control and difference subgroups of Group B

Subgroups compared	Mean ± SD	p-value*
Subgroup (i) Vs (ii)	10.89±0.67 5.84±0.84	<0.0001 (Sig.)
Subgroup (i) Vs (iii)	10.89±0.67 10.86±0.82	0.92 (NS.)
Subgroup (i) Vs (iv)	10.89±0.67 6.09±0.72	<0.0001 (Sig.)

* Students independent t-test was used to calculate the p-value

Mean value in Subgroup **(i)** is significantly higher than the mean values in subgroup **(ii)** and in subgroup **(iv)**.However, there is no significant difference in mean values between subgroup **(i)** and subgroup **(iii)**.

Table-X: Mean, Standard deviation and test of significance of mean values between subgroup iii Vs subgroups ii and iv of Group B

Subgroups compared	Mean ± SD	p-value*
Subgroup (iii) Vs (iv)	10.86±0.82 5.84±0.84	< 0.05
Subgroup (iii) Vs (iv)	10.86±0.82 6.09±0.72	< 0.05

* One way ANOVA was used to calculate 'p' value

One way ANOVA was done to compare the mean values of subgroups **(ii)**, **(iii)** and **(iv)** of Group B. It was found that the mean value in subgroup **(iii)** was significantly higher than the mean values in subgroups **(ii)** and **(iv).**

Table-XI: Mean, standard deviation, and test of significance of mean values between subgroups (ii) and (iv) of Group B

Sub groups compared	Mean±SD	p-value*
Subgroup (ii)	5.84±0.84	0.47(NS)
Subgroup (iv)	6.09±0.72	

* Student's independent t-test was used to calculate the p-value.

There is no significant difference in mean values between Sub-group (ii) and (iv) of Group B.

Table-XII: Mean, Standard deviation and test of significance of mean values between Group A and Group B

Groups compared	Mean ± SD	p-value*
Group A	79.92±10.36	< 0.0001 (Sig.)
Group B	8.42±2.60	

* Student's independent t-test was used to calculate the p-value

Mean value in Group A is significantly higher than the mean value in Group B.

Table-XIII: Mean, Standard deviation and test of significance of mean values between Group A and Group B for each subgroup

Subgroups compared	Group A	Group B	p-value*
	Mean ± SD	Mean ± SD	
Subgroup (i)	88.58±6.94	10.89±0.67	< 0.0001 (Sig.)
Subgroup (ii)	74.47±7.19	5.84±0.81	< 0.0001 (Sig.)
Subgroup (iii)	85.29±8.51	10.86±0.82	< 0.0001 (Sig.)
Subgroup (iv)	71.34±7.91	6.09±0.72	< 0.0001 (Sig.)

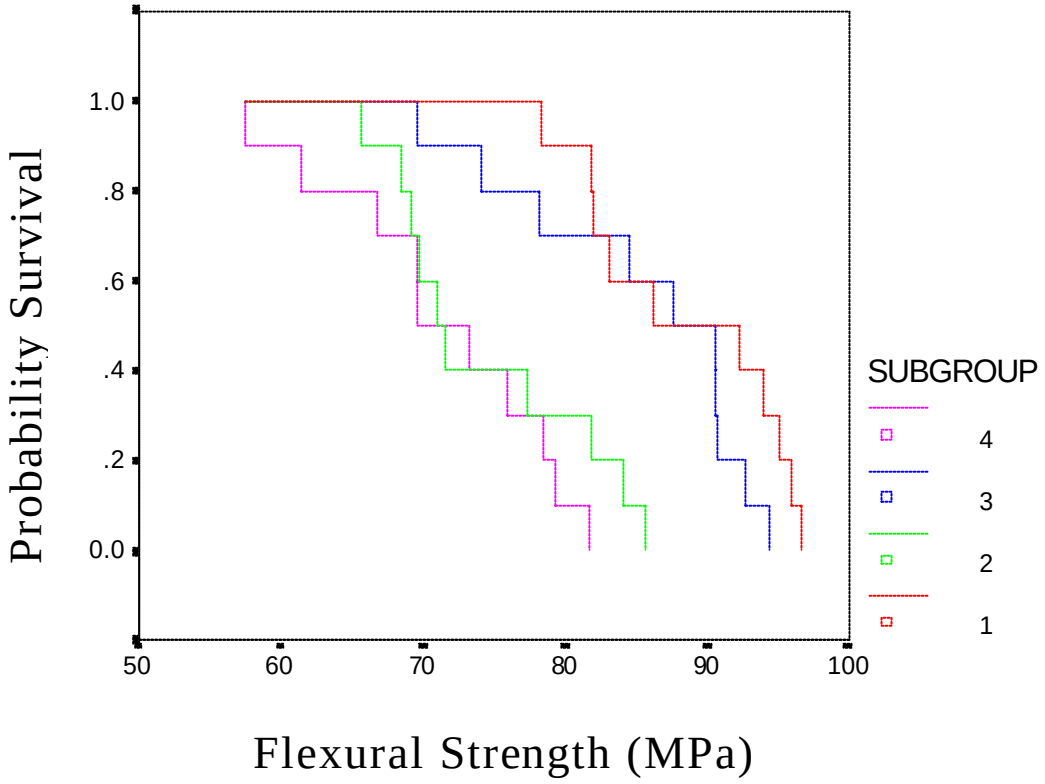
* Student's independent t-test was used to calculate the p-value.

For subgroup **(i)**, mean value in Group A is significantly higher than the mean value in Group B. For subgroup **(ii)**, mean value in Group A is significantly higher than the mean value in Group B. For subgroup **(iii)**, mean value in Group A is significantly higher than the mean value in Group B. For subgroup **(iv)**, mean value in Group A is significantly higher than the mean value in Group B.

KAPLAN MEIER'S SURVIVAL PROBABILITY ANALYSIS

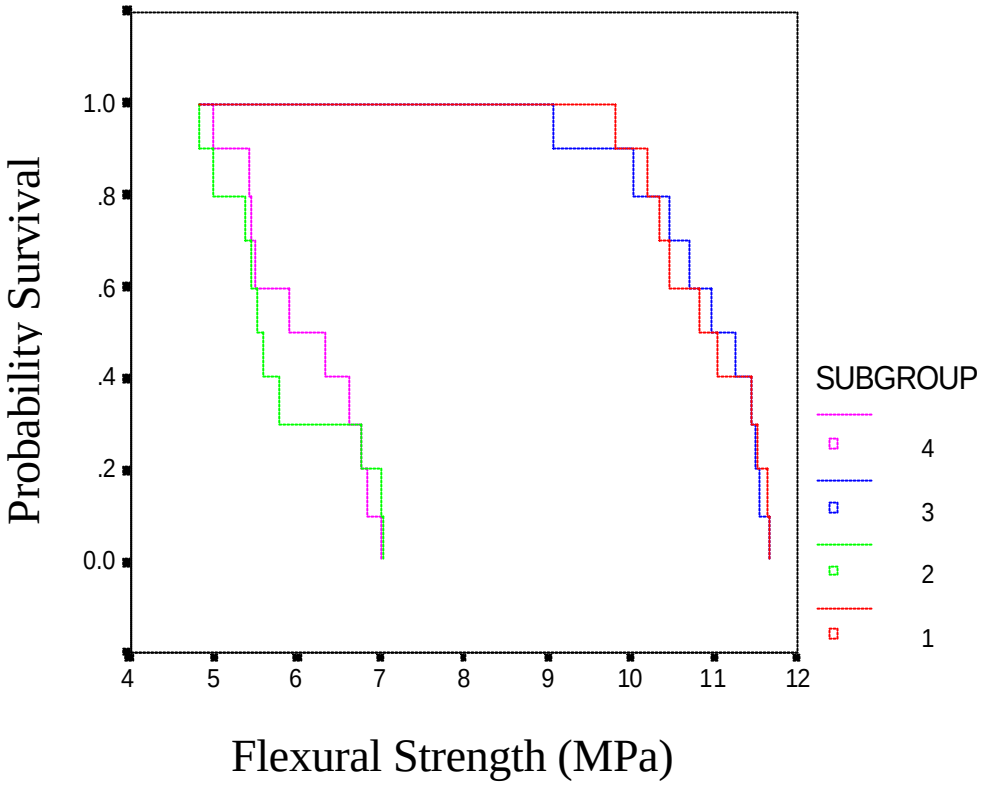
A survival probability analysis was done for Groups A (*laminate veneer*) and Group B (*laminate veneer luted with resin cement*).

Graph -2: Survival Analysis for Group - A



Graph-2 shows that the survival probability of subgroup **(i)** of Group A had a better chance of survival than all the subgroups. Subgroup **(ii)** had a better chance of survival than the subgroup **(iv)**.

Graph-3: Survival Analysis for Group - B



Graph-3 shows that the survival probability of subgroup **(i)** of Group B had a better chance of survival than all the subgroups. Subgroup **(iv)** had a better chance of survival than subgroup **(ii)**.

Scanning Electron Microscopic Analysis

Group A (Laminate Veneer)

Sub Group

(i) Control 37±1°C

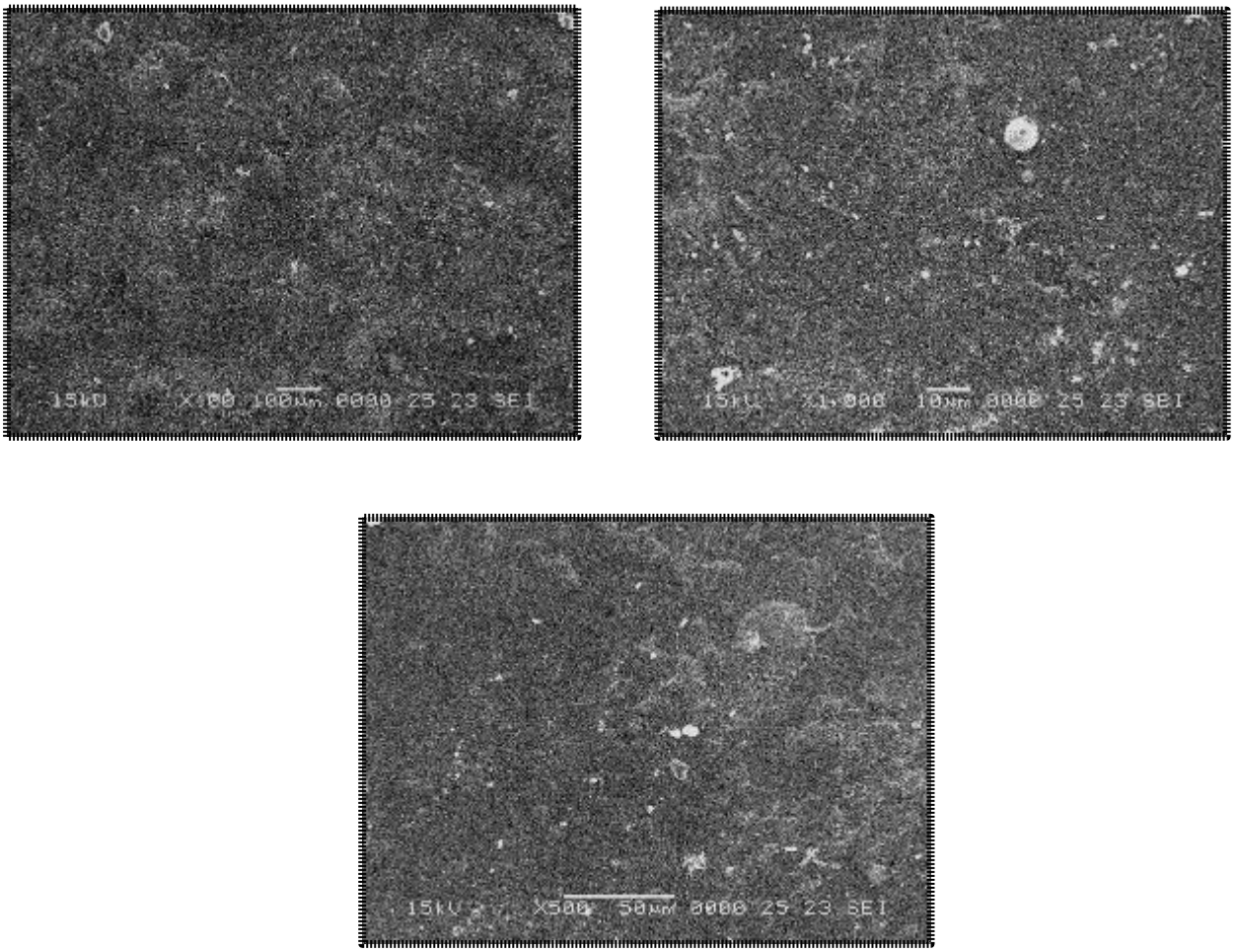


Fig-14 SEM picture of specimens belonging to Group A sub-group(i)- control (specimens kept at 37±1°C)

Sub Group

(ii) (4±1°C, 37±1°C)

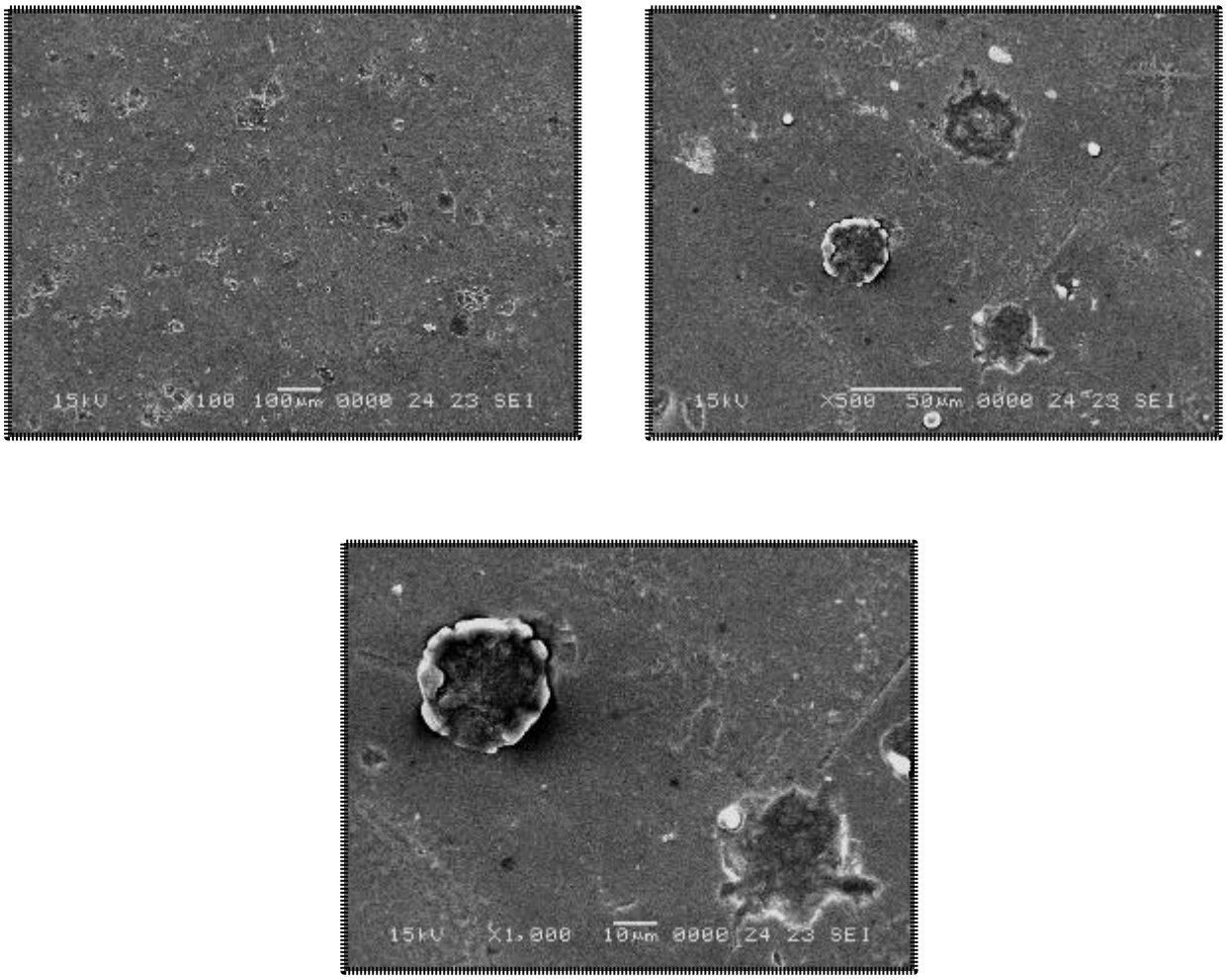


Fig-15: SEM picture of specimens belonging to Group-A sub-group (ii) (specimens thermocycled between 4±1°C and 37±1°C)

Sub Group

(iii) (37±1°C, 65±1°C)

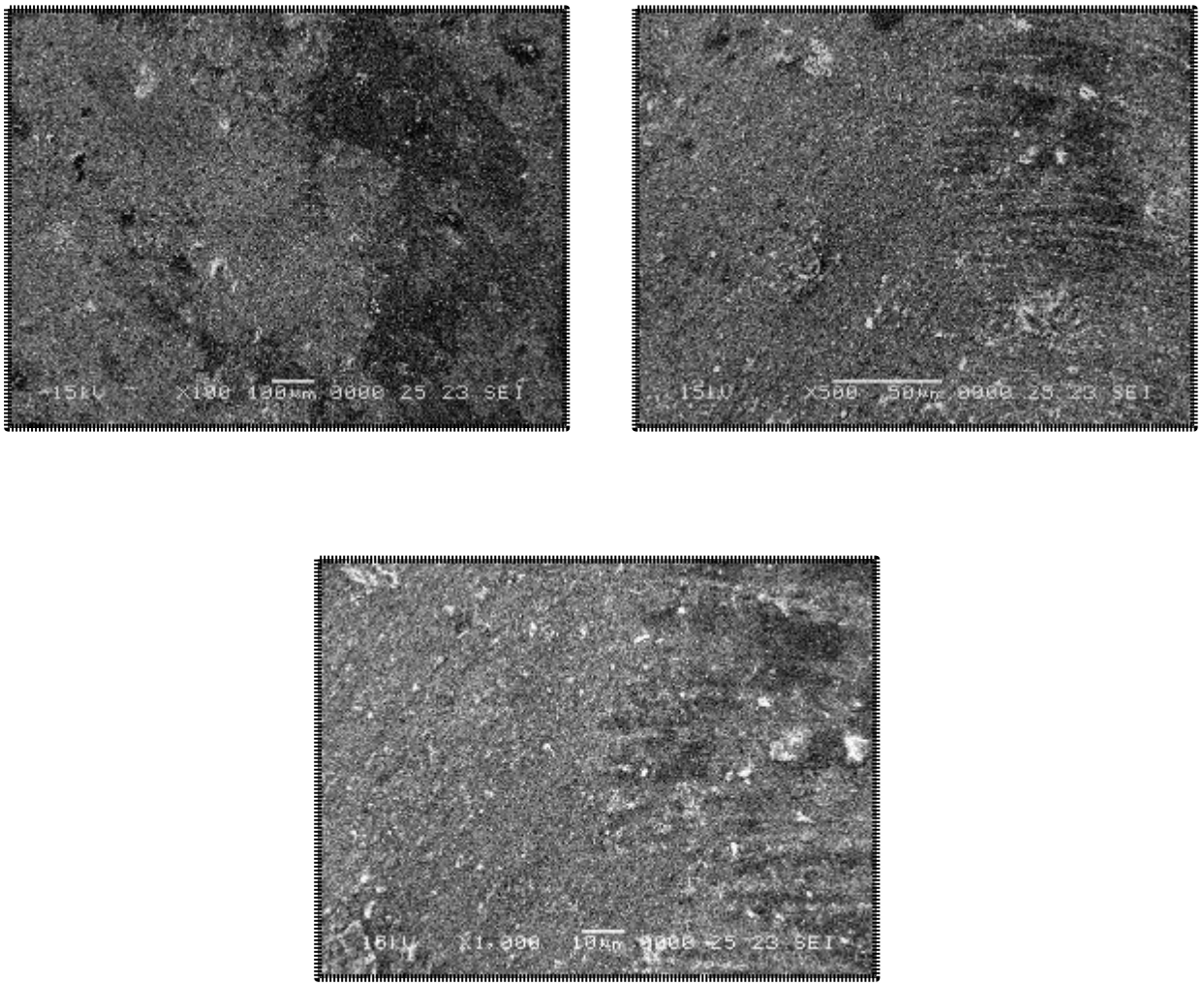


Fig-16: SEM picture of specimens belonging to Group-A sub-group (iii) (specimens thermocycled between 37±1°C and 65±1°C)

Sub Group

(iv) (4±1°C, 65±1°C)

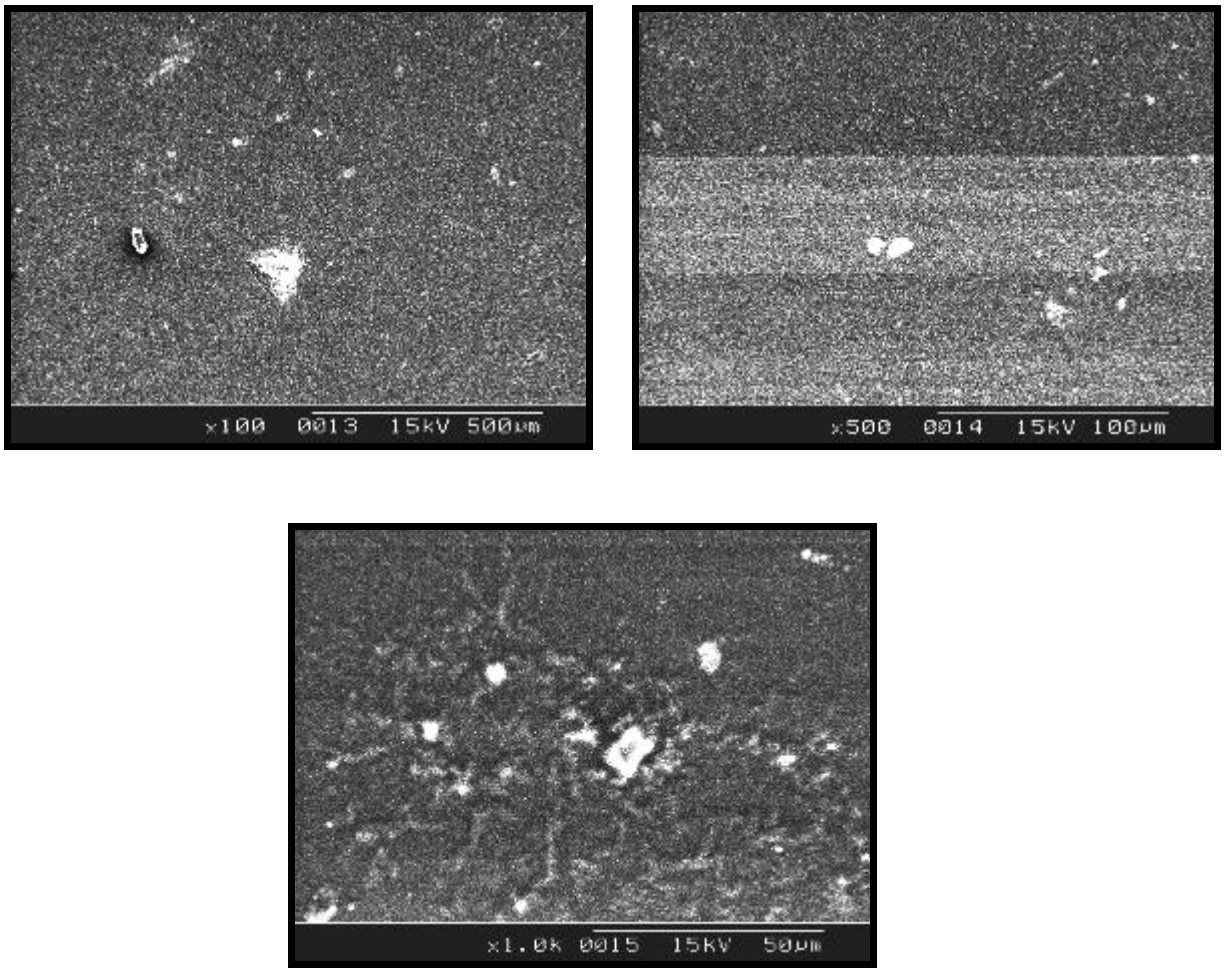


Fig-17: SEM picture of specimens belonging to Group-A sub-group (iv) (specimens thermocycled between 4±1°C and 65±1°C)

Scanning electron microscopic analysis of Group A specimens revealed no significant findings i.e. though the samples belonging to the sub-groups **(i)**, **(ii)**, **(iii)** and **(iv)** of Group A were thermocycled, no crack was found.

Group B (Laminate Veneer Luted With Resin Cement)

Sub Group

(i) Control 37±1°C

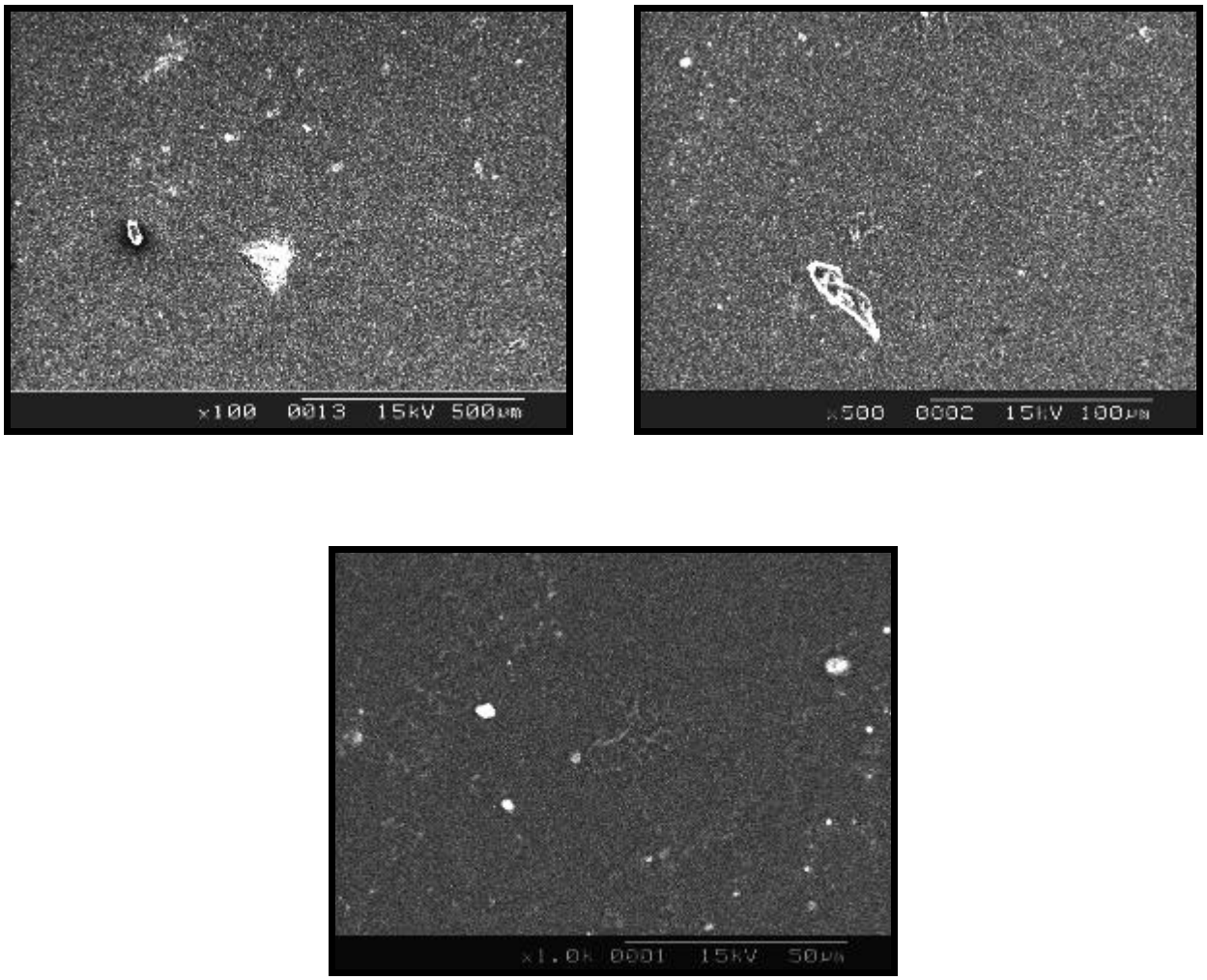
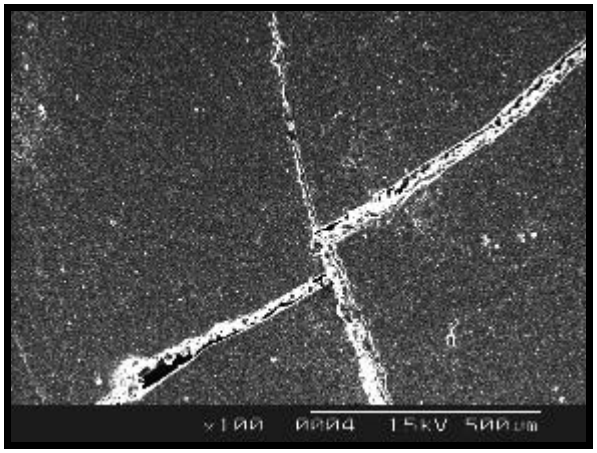
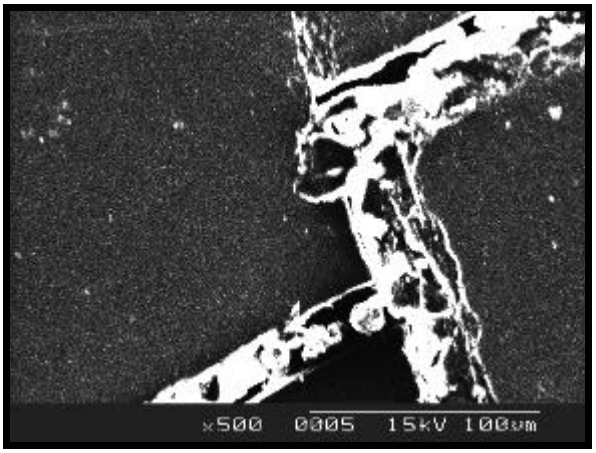


Fig-18: SEM picture of specimens belonging to Group-B sub-group (i)–control (specimens kept at 37±1°C)

Sub Group

(ii) (4±1°C, 37±1°C)





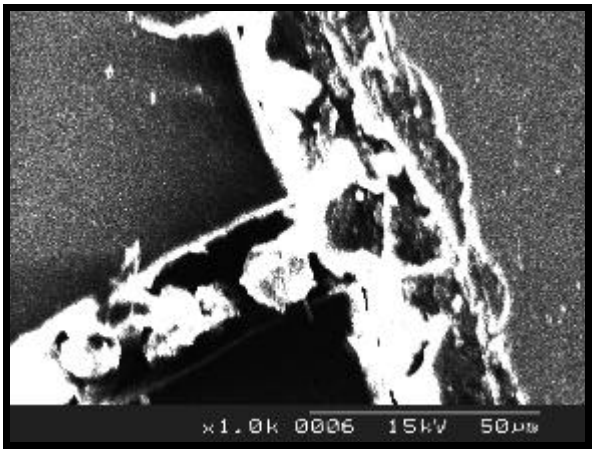


Fig-19: SEM picture of specimens belonging to Group-B sub-group (ii) specime ns thermocycled between 4±1°C and 37±1°C

Sub Group

(iii) (37±1°C, 65±1°C)

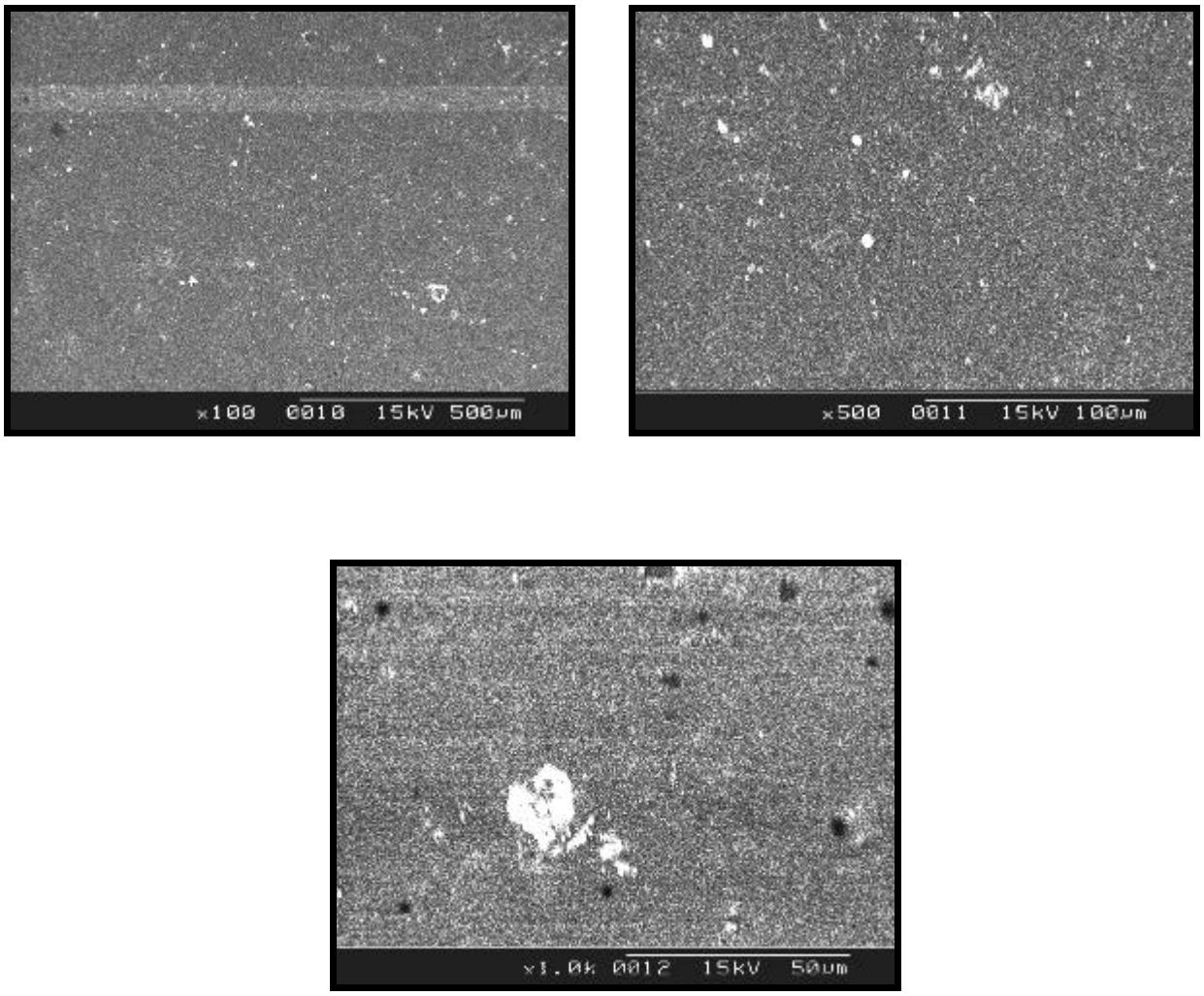


Fig-20: SEM picture of specimens belonging to Group-B sub-group (iii) (specimens thermocycled between 37±1°C and 65±1°C)

Sub Group

(iv) (4±1°C, 65±1°C)

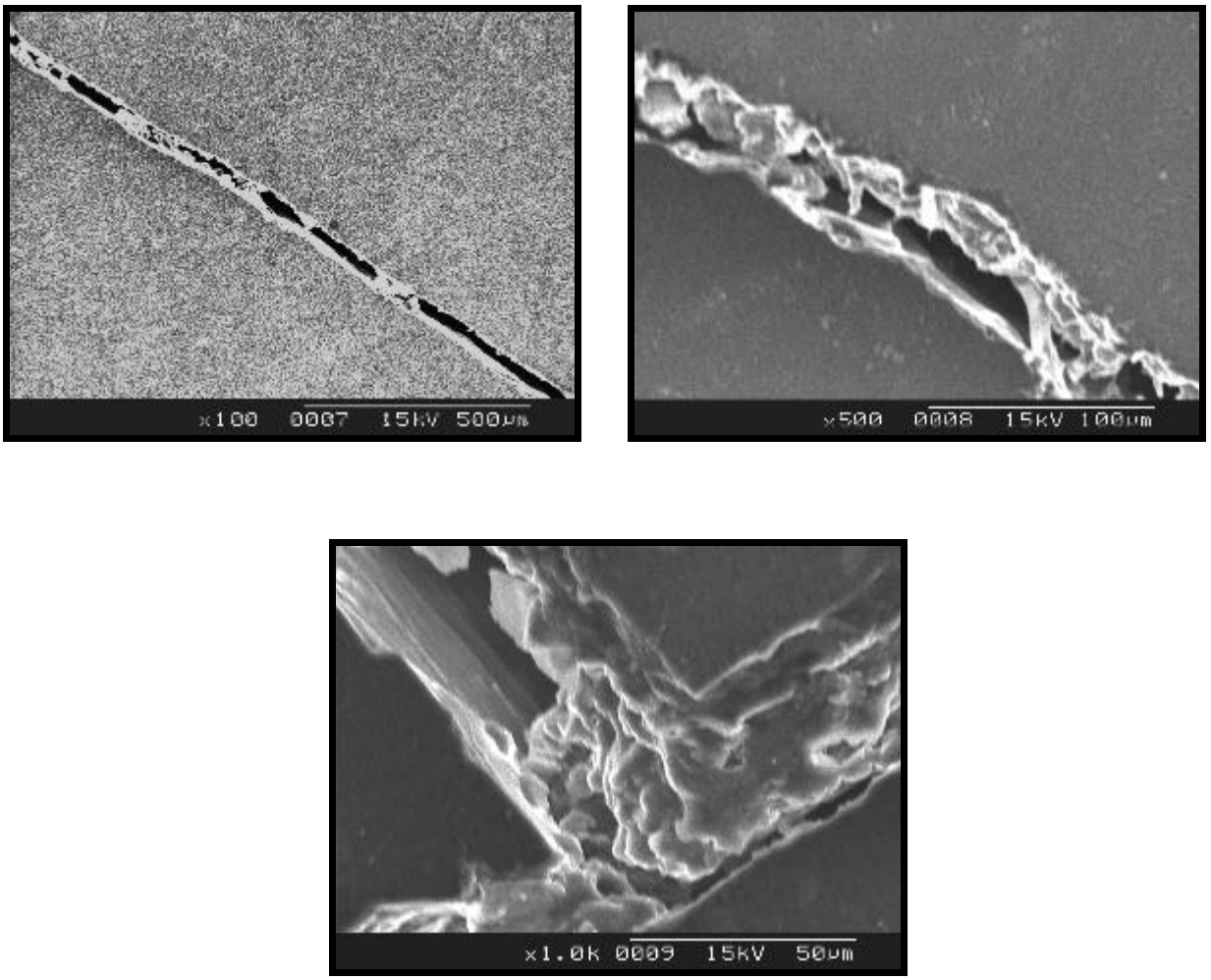


Fig-21: SEM picture of specimens belonging to Group-B sub-group (iv) (specimens thermocycled between 4±1°C and 65±1°C)

Scanning electron microscopic analysis of group B specimens revealed cracks propagating through the ceramic veneer in sub-groups (ii) and (iv)

Discussion

Brittle materials such as ceramics fail because of the formation and growth of microscopic flaws that can form during fabrication or service[4, 5, 23]. Ceramics are susceptible to slow crack growth at the tips of the surface flaws exposed to a moist environment as a result of hydrolysis of silicate bonds[25]. Studies by White et al[13] had shown that immersion in water as such decreased the static strength and increased the crack velocity of ceramics. Sherill and O'Brien[4, 8], Fairhurst et al[8], and Myers et al[8] had demonstrated a decrease in flexural strength of aluminous and feldspathic porcelains, when tested in water.

Further, surface flaws may become extended due to thermal variations induced by the ingested foods and drinks[25]. The effect of thermally induced stresses is an important aspect which has to be considered for any restoration. As attributed by Fleming et al[25], porcelain laminate veneers which are of only 0.5–0.9mm in thickness may fail clinically due to the flaws extended as a result of thermal variations. Therefore, the effect of thermocycling on the flexural strength of the laminate veneers and laminate veneers luted with resin cement was evaluated in our study. This was done to find out the effect of the luting agent on the flexural strength of the ceramic.

Disc specimens were fabricated for the study because the effect of flaws common with rectangular bars could be avoided[11]. Further, these tests are relatively insensitive to specimen geometry and flaw direction. The surfaces of the discs were glazed to mimic the final restoration. Studies by Giordano et al[9] had demonstrated that a glaze placed on the surface increased the strength by inhibiting crack propagation through the compressive stresses generated on the surface of the ceramic during cooling. Further studies by Chu et al[19] had proved that if firing conditions are controlled properly, self-glazing was the most appropriate procedure to be carried out to control surface flaws without losing the surface features of porcelain restorations. An appropriate firing cycle as recommended by the manufacturer was used to fire porcelain.

Table-I: **Firing cycle**

Air fired	600^0C for 360 seconds
Vacuum fired	970^0C for 60 seconds
Air fired	970^0C for 60 seconds

Porosity has an effect on crack propagation behavior of the ceramics. Anusavice et al[4] in their studies pointed out that irregular, non-spherical voids facilitated crack initiation when subjected to transient incompatibility stress below the threshold value and not the spherical voids. Samples in our study had spherical voids and

reasonably it can be deducted that they have not affected the strength property of the material.

Thermocycling regime was carried out between the maximum and minimum temperatures i.e. (65 ± 1^0C and 5 ± 1^0C) with the closed mouth temperature (37 ± 1^0C).this is in accordance with the study by Palmer[6] who showed that the maximum and minimum temperature extremes in an oral cavity ranged between 0 and 65°C.

These temperature extremes were selected because it would maximize the effect that thermocycling would have on the longevity of porcelain laminate veneers. In the oral environment high and low temperatures are only transient, and to stimulate the clinical situation, a short dwell time (*5 seconds*) was used in the study.

3500 cycles was chosen to approximate one year of clinical service for a porcelain laminate veneer restoration[25],assuming that at most 10 extreme thermocycles would occur a day

After subjecting the samples to thermocycling, they were subjected to scanning electron microscopy. This was done to find out whether the presence of moisture and thermocycling accelerated crack propagation. SEM analysis revealed crack propagation in the samples of group B where ceramic discs were luted to resin cement and subjected to temperatures of (5 ± 1^0C and 37 ± 1^0C) (i.e.) sub-group (ii) and (5 ± 1^0C and 65 ± 1^0C) sub-group (iv).

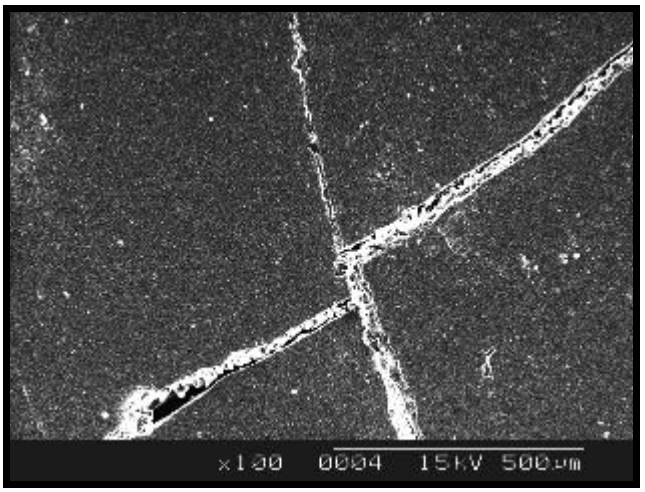


Fig-22: SEM picture of specimens belonging to sub group (ii) of Group B

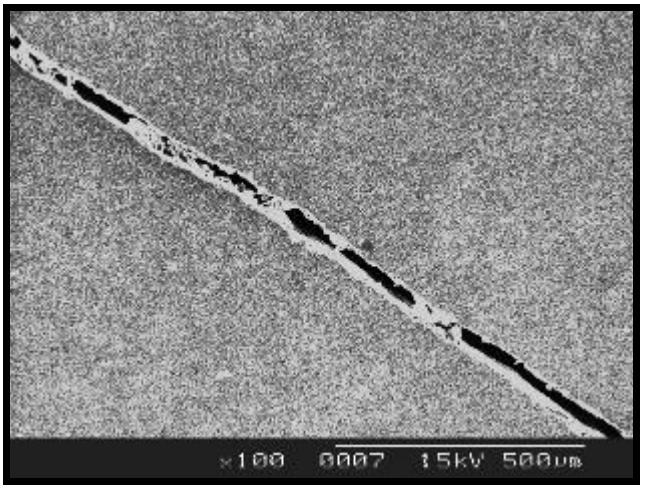


Fig-23: SEM picture of specimens belonging to sub group (iv) of Group B

As demonstrated by Magne et al[18], the occurrence of cracks was due to thermal variation that generated a cyclic mechanical load that resulted from the differential thermal expansion of the luting agent and the ceramic veneer. The co-efficient of thermal expansion of luting agent and porcelain veneer being $30/°C \times 10^{-6}$ and $8/°C \times 10^{-6}$ respectively.

The laminate seemed to act as a rigid shell with high elastic modulus that restrained the dimensional change of the underlying cement. Ceramic cracks are found only when it is thermocycled and not on simple storage in water. The static stress produced by the shrinkage of the luting agent was not directly related to the development of flaws, but its combination with repeated thermal loads demonstrated a cumulative damage to the ceramic veneer.

Flexural strength of the specimens were found out because the strength of the brittle materials are usually measured in flexure[29] i.e. bending, because this test is generally easier to perform than a pure tensile test. In flexure (bending), the tensile stress reaches to maximum on the superior surface and compressive stress reaches a maximum on the inferior surface. Kelly et al[5] attributed that failure of all-ceramic restorations usually originate on their inner aspects remote from the point of load application Therefore flexure tests provide valuable information on the tensile strength of the ceramic. Flexure strength was used thus as a measure of crack propagation from surface micro-cracks. Further the test was uncomplicated, inexpensive, did not require complex instrumentation and required geometrically simple specimens[13].

Blunt-indentation technique suggested by White was used to find the susceptibility of porcelain to mechanical fatigue. This

technique was used because unlike sharp indenters, blunt contact favored in evaluating evolution of damage[7, 13]. Breaking load values were obtained for the ceramic discs of Group A (*laminate veneer*) and Group B (*laminate veneer luted with resin cement*) by subjecting them to a tensile loading in a universal testing machine (*Instron*).The flexural strength values for Group A were then calculated using Timoshenko's equation[25].The flexural strength values for Group B was evaluated using a formula for bilayered discs as proposed by Isgro et al[27].

It was found that Group A had superior flexural strength than Group B. Within the Groups A and B, subgroup (i) (control) had a superior flexural strength when compared with sub groups (ii) and (iv) that are subjected to extremes of temperatures.

The flexural strength analysis revealed decreased strength of specimens of both Groups A and B subjected to extremes of temperature. This showed that lower temperatures had a deteoriating effect on the flexural strength of laminate veneers and laminate veneers luted with resin cement.

The specimens of Group A when subjected to extremes of temperatures, (4 ± 1^0C and 37 ± 1^0C) and (4 ± 1^0C and 65 ± 1^0C), superficial surface of the veneer reached the new temperature

instantaneously, but the inner surface did not attain the same temperature. This difference resulted in a detrimental tensile stress at the veneer surface causing decreased flexural strength[25].

Among A and B, Group B (*laminate veneers luted with resin cement*) showed a marked decrease in flexural strength than Group A (*laminate veneers only*).As seen in SEM, the strength obtained was due to the elastic modulus of the resin cement as the ceramic veneer had already cracked. Among the specimens in group B, those subjected to extremes of temperature (4 ± 1^0C and 37 ± 1^0C) and (4 ± 1^0C and 65 ± 1^0C) had a decrease in their flexural strength. This might be due to

- Thermal variations which induced tensile stresses on the ceramic veneers[18].
- Difference in co-efficient of thermal expansion and elastic modulus between the ceramic and the resin cement. As reported by Shehri et al[15], strength of two materials with different properties when joined together was influenced by the differences in their properties (i.e.) larger the difference in co-efficient of thermal expansion, lower was the flexural strength.
- Shrinkage of the resin cement that caused crack propagation and ultimately failure of the specimens. The study by

Magne et al[18] proved that neither the low elastic modulus nor the elasticity of the underlying tissues were sufficient to overcome the repeated thermal stresses produced by the dimensional change of the luting material which inhibited crack propagation.

- Water played the role of plasticizer seeping into the resin cement decreasing the elastic modulus of the resin further. Studies by Sobrinho et al[17] had demonstrated that in addition to moisture, stress corrosion cracking accelerated in alumina or high alumina systems and the most significant source of moisture ingress was via the cement.

Summary and Conclusions

This study was conduced to assess the influence of thermocyling on the flexural strength of porcelain laminate veneers. 80 discs of 10mm diameter and 0.9mm thickness were made with Vitadur alpha dentin powder by using a metallic mold. They were glazed on one side. The specimens were divided into two Groups A and B, each containing 40 discs. The specimens in Group A consisted of porcelain laminate veneer only. In the disc specimens of Group B resin cement was luted on to their inner non-glazed surface to simulate clinical condition. The cement thickness was standardized to 0.2mm.

The discs in Group A and B were randomly divided into four subgroups each. The subgroups were subjected to thermocycling under different temperatures. After thermocycling the specimens were examined under SEM for evaluating crack formation if any after thermocycling. Breaking load values were obtained for the specimens using universal testing machine (INSTRON), by loading the discs with a metallic fixture. Flexural strength was calculated for Groups A

and B using Timoshenko's equation and formula for bilayered discs respectively.

The data obtained were statistically analyzed using Student's independent 't' test, one-way ANOVA and Kaplan Meier's survival probability analysis to find

- Level of significance of mean values between control and subgroups of both A and B Groups.
- Level of significance of mean values between Group A and B.
- Level of significance of mean values between Group A and B for each sub group.
- Survival probability of specimens in A and B respectively

The conclusions drawn from the study are

- Laminate veneer specimens exhibited greater flexural strength than those which were luted with resin cements
- Laminate veneer specimens luted with resin cement when subjected to extremes of temperature (4 ± 1^0C and 37 ± 1^0C) and (4 ± 1^0C and 65 ± 1^0C) showed marked decrease in flexural strength

- Laminate veneer specimens luted with resin cement after thermocycling at extremes of temperature showed crack propagation

The clinical implications are

- Fit of laminate veneers cannot/ should not be compensated by thickness of luting agent. As the resin cement used for luting porcelain laminate veneer actually decreases the flexural strength and causes crack propagation in the laminate veneer. The crack propagation in the laminate veneer was possibly due to
    - Difference in the co-efficient of thermal expansion and elastic modulus between ceramic and resin cement
    - Water seeping into the resin cement that decreased the elastic modulus of the resin further when subjected to thermocycling
- During the laboratory phase of porcelain laminate veneer fabrication, the die spacer must be applied carefully to form a uniform layer. This is to avoid excessive thickness of luting cement that would reduce the ceramic and luting cement ratio.

- Tooth reduction must be sufficient to ensure uniform ceramic thickness in the final restoration that would provide favorable ceramic and luting cement ratio.

References

1. **Crim GA, Swartz ML, Phillips RW:** Comparison of four thermocycling techniques. J Prosthet Dent 1985; 53:50-52.
2. **Morena R, Beaudreau GM, Lockwood PE, Evans AL, Fairhurst CW:** Fatigue of dental ceramics in a simulated oral environment. J Dent Res.1986; 65: 993-997.
3. **Anusavice KJ, DeHoff PH, Hojjatie B, Gray A:**Influence of tempering and contraction mismatch on crack development in ceramic surfaces. J Dent Res 1989;68: 1182-1187
4. **Anusavice KJ, Lee RB:** Effect of firing temperature and water exposure on crack propagation in unglazed porcelain. J Dent Res 1989; 68: 1075-1081.
5. **Kelly JR, Campbell SD,Bowen HK:** Fracture-surface analysis of dental ceramics. J Prosthet Dent 1989; 62:536-541.

6 **Palmer DS, Barco MT,Billy EJ:** Temperature extremes produced orally by hot and cold liquids. J Prosthet Dent 1992; 67; 325-327

7 **White SN:** Mechanical fatigue of a feldspathic dental porcelain. Dent Materials 1993; 9: 260-264.

8 **Edge MJ, Wagner WC**: Surface cracking identified in polished and self-glazed dental porcelain. J Prosthod 1994; 3: 130-133.

9 **Giordano RA, Campbell S, Pober R:** Flexural strength of feldspathic porcelain treated with ion exchange, overglaze, and polishing. J Prosthet Dent 1994; 71:468-47.

10 **Myers ML, Ergle JW, Fairhurst CW, Ringle RD:** Fatigue characteristics of a high strength porcelain. Int J Prosthodont 1994; 7: 253-257.

11 **Giordano RA, Cima M, Pober R:** Effect of surface finish on the flexural strength of feldspathic and aluminous dental ceramics. . Int J Prosthodont 1995;8: 311-319

12 **Giordano RA, Pelletier L, Campbell S, Pober R:** Flexural strength of an infused ceramic, glass ceramic and feldspathic porcelain. J Prosthet Dent 1995; 73: 411-418.

13 **White SN, Zhan XY, Yu Z, Li ZC, Kipnis V:**Cyclic mechanical fatigue of a feldspathic dental porcelain. Int J Prosthodont 1995; 8: 413-420.

14 **Harvey CK, Kelly JR:** Contact damage as a failure mode during in vitro testing. J Prosthodont 1996; 5:95-100.

15 **Sherhri SAA, Mohammed H, Wilson CA:** Influence of lamination on the flexural strength of a castable glass ceramic. J Prosthet Dent 1996; 76:23-28.

16 **Catell MJ, Clarke RL, Lynch EJ:** The biaxial flexural strength and reliability of four dental ceramics. J Dent 1997; 25: 409-414

17 **Sobrinho LC ,Catell MJ, Glover RH, Knowles JC** Investigation of the dry and wet fatigue properties of three all-ceramic crown systems. Int J Prosthodont 1998; 11: 255-262

18 **Magne P, Dr Med Dent, Kwon K, Belser UC, Hodges JS, Douglas WH:** Crack Propensity of porcelain laminate veneers: A simulated operatory evaluation. J Prosthet Dent 1999; 81: 327-334.

19 **Chu FCS, Frankel N, Roger, Smales J:** Surface roughness and flexural strength of self-glazed, polished, and reglazed In-Ceram/ Vitadur Alpha porcelain laminates. Int J Prosthodont 2000; 13:66-71.

20 **Fleming GJP, Shaini FJ, Marquis PM:** An assessment of the influence of mixing induced variability on the bi-axial flexural strength of dentine porcelain discs and the implications for laboratory testing of porcelain specimens. Dent Materials 2000; 16:114-119.

21 **Scherrer SS, Denry IL, Wiskott HWA, Belser UC:** Effect of water exposure on the fracture toughness and flexure strength of a dental glass. Dent Materials 2001; 17:367-371.

22 **Aristidis GA, Dimitra B:** Five- year clinical performances of porcelain laminate veneers. Quintessence International 2000; 2: 22-25.

23 **Bona AD, Anusavice KJ, Dehoff PH:** Weibull analysis and flexural strength of hot pressed core and veneered ceramic structures. Dent Materials 2003;19: 662-669

24 **Flanders LA, Quinn JB, Wilson OC, Lloyd IK:** Scratch hardness and chipping of dental ceramics under different environments. Dent Materials 2003; 19: 716-724.

25 **Addison O, Fleming GJP, Marquis PM:** The effect of thermocycling on the strength of porcelain laminate veneers. Dent Materials 2003; 19:291-297

26 **Griggs JA, Kishen A, Le KN:** Mechanism of strength increase for a hydrothermal porcelain. Dent Materials 2003;19: 625-631

27 **Isgro G, Pallav P, Zel JMVD, Feilzer AJ:** The influence of the veneering porcelain and different surface treatments on the biaxial flexural strength of a heat-pressed ceramic. J Prosthet Dent 2003; 90: 465-473.

28 **Thompson GA:** Determining the slow crack growth parameter and weibull two-parameter estimates of bilaminate disks by constant displacement-rate flexural testing. Dent Materials 2004; 20: 51-62.

29 **Brien WJO:** Dental Materials and these selection, ed 2, Quintessence Publishing Company, 1997.

30 **Anusavice KJ:** Philips' science of dental materials, ed 10, Bangalore, WB Saunders Company, 1998.

Appendix

Table XIV: Breaking load values of Group A specimens (porcelain laminate veneers)

Test Samples	Sub Group (i)	Sub Group (ii)	Sub Group (iii)	Sub Group (iv)
(n)	Breaking Load (Kg)	Breaking Load (Kg)	Breaking Load (Kg)	Breaking Load (Kg)
1	3.289	3.263	3.221	2.993
2	3.685	2.725	3.597	2.188
3	3.120	2.658	2.980	2.652
4	2.988	2.950	3.530	2.789
5	3.650	3.121	3.452	3.021
6	3.165	3.205	3.339	2.653
7	3.580	2.708	3.458	2.892
8	3.522	2.612	2.650	2.345
9	3.126	2.635	2.824	2.542
10	3.625	2.502	3.450	3.112

Table XV: Breaking load values of Group B specimens (porcelain laminate veneers luted with resin cement)

Test Samples	Sub Group (i)	Sub Group (ii)	Sub Group (iii)	Sub Group (iv)
(n)	Breaking Load (Kg)	Breaking Load (Kg)	Breaking Load (Kg)	Breaking Load (Kg)
1	8.134	4.644	7.517	5.799
2	9.624	4.128	9.651	4.500
3	8.560	4.510	8.289	4.490
4	9.125	5.800	8.650	4.125
5	9.550	4.450	9.540	5.605
6	9.650	5.600	9.050	5.485
7	8.950	5.820	8.855	5.645
8	9.450	4.780	9.300	4.560
9	8.425	3.985	9.450	4.890
10	8.655	4.565	9.500	5.250